JOURNAL OF AGRICULTURAL RESEARCH

VOL. X WASHINGTON, D. C., SEPTEMBER 17, 1917 NO. 12

EFFECT OF THREE ANNUAL APPLICATIONS OF BORON ON WHEAT

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INTRODUCTION

The object of these experiments was to determine whether or not boron when applied to horse manure in quantities sufficient to act as a fly larvicide would have a cumulative action detrimental to wheat (*Triticum* spp.) grown on soil fertilized with this manure for three consecutive years.

EXPERIMENTAL WORK

Four plots of one-twentieth of an acre each on the farm of the Bureau of Plant Industry at Arlington, Virginia, were used for the experiments. One plot was used as a manured control and a second as an unmanured control. The third plot received manure plus borax, and the fourth manure plus colemanite. The manure was applied to all plots at the rate of 20 tons per acre, and the same variety of winter wheat was planted each year on all the plots. Borax was mixed with the manure the first year, (1913), at the rate of 0.33 pound per bushel. The last two years (1914 and 1915) the borax was mixed with the manure at the rate of 0.08 pound per bushel, and the colemanite was mixed with a second pile of manure at the rate of 0.095 pound per bushel.

It was calculated that when borax was mixed with manure at the rate of 0.08 pound per bushel and the manure applied at the rate of 20 tons per acre an equivalent of 0.0022 per cent boric acid (H_3BO_3) was present in the upper 6 inches of the soil. In the same way it was calculated for the colemanite plot that an equivalent of 0.0029 per cent of boric acid was present in the upper 6 inches of soil. The amount of borax added the first year, 0.33 pound per bushel, furnished 0.0088 per cent of boric acid to the upper 6 inches of soil.

The above figures show that the boron was applied as follows: The borax plot received boron the first year at the rate of 154 pounds of boric acid per acre and the second and third years at the rate of 38.5 pounds per acre. The colemanite plots received boron at the rate of 50.75 pounds of boric acid per acre each year.

Colemanite, a borate of lime, is found in the deposits of Ventura County, Cal. Its formula is $Ca_2B_6O_{11}.5H_2O$. On heating, the water is driven off, and it is reduced to a grayish white powder. The calcined colemanite is largely, but not entirely, insoluble in cold water. It is also likely that part of the calcium of the colemanite when added to the soil is precipitated as carbonate, and the boron in the compound thus acted upon is rendered soluble.

EFFECT OF THE BORON ON THE WHEAT

The wheat was planted each year in October a few days after the manure had been applied to the plots, and the growth was observed throughout the year. The crops were harvested the next June. Soil, straw, and grain samples were taken at the time of harvest for chemical analyses. The first year there was considerable yellowing of the young wheat plants in the borax plot, commencing in November and extending to the growing period the next spring, when it disappeared. This yellowing was not noticed the last two years when the amounts of boron added to the manure were reduced to amounts sufficient to act as a larvicide. There were no differences in the stand or appearance of the wheat on either the borax, colemanite, or manured control plots in 1915 or 1916. Each year the unmanured control showed the poorest stand. The yields of straw and grain from all the plots are given in Table I.

TABLE I.—*Yield of wheat at Arlington, Va., for three years, 1914–1916, from same plots ($\frac{1}{10}$ acre), fertilized annually with manure treated with borax and colemanite*

Treatment.	Yield (pounds).					
	1914		1915		1916	
	Straw.	Grain.	Straw.	Grain.	Straw.	Grain.
Manure and borax	204	104	159	89	284	79
Manure and colemanite	.....	.....	152	99	240	[a] 68
Manured control	234	116	173	103	204	72
Unmanured control	174	100	158	78	192	77

[a] These shocks were badly eaten by rats.

YIELDS OF STRAW AND GRAIN

The results in Table I show that the largest yield of grain was from the manured control plot, with the exception of 1916, when the borax plot showed the largest yield. The straw yield for 1916 was also highest on the borax plot, while the 1914 and 1915 straw yields were highest on the manured control. There was some loss from the colemanite plot in 1916 as rats ate part of the grain while it was standing in the field after cutting. A gradual reduction in the yield of grain each year from all plots is noticed. During 1916 there was a marked tendency toward the production of straw at the expense of grain, the ratios of straw to grain being 2 to 1 or under for 1914 and 1915, while it was 2.5 to 3 to 1

for 1916 on all plots. It is apparent that during 1914 and 1915, when there was a good growth on all plots, the borax had reduced the yield of grain over that of the manured control. The yields of grain from the borax plots both years were in excess of the yields from the unmanured control. The colemanite had little, if any, influence on the yields. During 1916, which was a poor year for wheat in this vicinity, the results do not show any effect of the boron. There was no apparent cumulative action of the boron in the soil. The yields of grain the first two years from the borax plots were 12 to 14 pounds under that of the manured control, while the third year (1916) the yield was 7 pounds more than that of the manured control.

ANALYSES OF STRAW AND GRAIN

In Table II are given results of the analyses of samples of straw and grain each year from all the plots. Water, ether extract, and nitrogen were determined by the methods of the Association of Official Agricultural Chemists.[1] The boric acid was determined in the straw and grain by the method described by the senior author (3, p. 879),[2] who used strips of paper dipped in an alcoholic solution of curcumin and compared the resulting color with that from standard solutions of boric acid.

TABLE II.—*Analyses of wheat straw and grain grown on plots fertilized for three years with manure containing added borax and colemanite, at Arlington, Va.*

Year.	Plot treatment.	Sample.	Constituents (per cent).			
			Moisture.	Ether extract.	Nitrogen.	Boric acid.
1914	Manure and borax.....	Grain.....	11. 14	1. 70	2. 15	Trace.
		Straw.....	2. 55	2. 12	. 28	Trace.
1915	.....do.....	Grain.....	9. 18	1. 71	2. 21	0. 00005
		Straw.....	4. 88	1. 13	. 51	0
1916	.....do.....	Grain.....	9. 19	. 97	2. 72	. 0006
		Straw.....	5. 87	. 91	. 62	. 00070
1914	Manure and colemanite	Grain.....	.....	.....	.....	.....
		Straw.....	.....	.....	.....	.....
1915	.....do.....	Grain.....	9. 76	1. 80	2. 40	. 00008
		Straw.....	4. 98	1. 20	. 58	0
1916	.....do.....	Grain.....	8. 95	. 99	2. 84	. 00025
		Straw.....	6. 03	. 92	. 69	. 00050
1914	Manured control.....	Grain.....	12. 58	1. 77	2. 21	0
		Straw.....	2. 53	2. 27	. 32	0
1915	.....do.....	Grain.....	9. 60	1. 55	2. 24	0
		Straw.....	6. 72	1. 28	. 48	0
1916	.....do.....	Grain.....	8. 86	1. 13	2. 91	. 0001
		Straw.....	5. 53	. 81	. 70	Trace.
1914	Unmanured control....	Grain.....	.....	.....	.....	.....
		Straw.....	.....	.....	.....	.....
1915	.....do.....	Grain.....	.....	.....	.....	.....
		Straw.....	.....	.....	.....	.....
1916	.....do.....	Grain.....	9. 12	1. 13	2. 56	Trace.
		Straw.....	4. 90	. 95	. 49	Trace.

[1] WILEY, H. W., ed. OFFICIAL AND PROVISIONAL METHODS OF ANALYSIS, ASSOCIATION OF OFFICIAL AGRICULTURAL CHEMISTS. AS COMPILED BY THE COMMITTEE ON REVISION OF METHODS. U. S. Dept. Agr. Bur. Chem. Bul. 107 (rev.), p. 38–39. 1908.

[2] Reference is made by number to "Literature cited", p. 597.

Somewhat more boric acid was found in the grain and straw grown in 1916 than in that grown in 1915, while the smallest percentage of boric acid was found in the 1914 samples. Even after applying borax or colemanite to the same ground for 3 years, very little boron was taken up by the plants grown the third season. A little more boron was absorbed by the plants grown on the plots fertilized with manure containing borax than by the plants grown on the plots fertilized with manure to which colemanite had been added. In the pot tests reported by Cook (3) the same tendency for wheat plants grown on soil containing added borax to absorb more boron than plants grown on soil containing added colemanite was observed. The water figures were lower in the grain and higher in the straw each successive year, and there was a marked reduction each year in the ether extract of both wheat and straw from all plots, but an increased nitrogen content. The average figures show a little more water, fat, and nitrogen in the manured-control wheat and straw than in the borax-manure samples of wheat and straw.

The distribution of the boron between the grain and straw samples tested was nearly equal. In 1915 the roots of some plants from each plot were tested for boric acid with the following results: Borax plot 0.00007 per cent, colemanite plot 0.00007 per cent, and control plot 0.

ANALYSES OF SOIL SAMPLES

In Table III analyses of samples of soil taken from the various plots are recorded for each of the three years. The methods used for total nitrogen and ammonia (magnesium-oxid distillation process) were those of the Association of Official Agricultural Chemists.[1] The aeration method as outlined by Folin and Macallum (4) for the determination of ammonia and the nitrate method of the American Public Health Association (2) were employed. Both acid soluble and total boric acid were determined in each sample. For soluble boron 50 gm. of soil and 200 c. c. of 1–20 hydrochloric acid were shaken for one hour. The filtrate was made alkaline with lime, evaporated to dryness, and ashed. The ash was taken up in hydrochloric acid, diluted to 100 c. c. volume, and aliquots used for the colorimetric estimation of boron. The total boron was estimated by fusion of the soil sample with sodium hydroxid. In both cases the colorimetric method, with strips of curcumin paper, was employed for estimating the boron. It is apparent that the boron in the soil is combined in some insoluble form, such as a silicate, and can be estimated only by a fusion process.

[1] WILEY, H. W. Op. cit.

TABLE III.—*Analyses of samples of soil taken 8 inches deep from wheat plots at Arlington, Va., fertilized for three consecutive years with manure treated with borax and colemanite*

Year and treatment.	Per cent of nitrogen as—				Percentage of boric acid.	
	Total nitrogen.	NH_3 (MgO method).	NH_3 (Folin method).	NO_3.	Hydrochloric acid, soluble.	Total.
1914.						
Borax	0.09	0.004	.....	0.0018	0.003	.....
Control manured	.09	.003	.....	.0012	0	.....
1915.						
Borax	.175	.014	0.0017	.0010	0	0.00016
Colemanite	.140	.014	.0016	.0012	0	.00040
Control manured	.126	.028	.0016	.0020	0	Faint trace.
1916.						
Borax	.074	.021	.0007	.0009	0	.00018
Colemanite	.105	.025	.0007	.0009	0	.00024
Control manured	.112	.025	.0007	.0013	0	.00014

There is considerable variation in the total nitrogen results, undoubtedly due to the sampling. The nitrogen as ammonia, by the magnesium-oxid method, showed a gradual increase in all samples from 1914 to 1916. The ammonia results by the Folin aeration method were higher in the 1915 samples, where the highest total nitrogen results were obtained, than in the 1916 samples. The soil to which either borax or colemanite was added showed less nitrate nitrogen than the control samples for the years 1915 and 1916, while the borax-plot sample showed more nitrates than the control in 1914. The only sample that showed any boric acid soluble in weak hydrochloric acid was from the borax plot in 1914, following the very heavy application of borax that year. This plot showed a distinct injury to the wheat the same year. The results for total boric acid showed that considerably more boron was present in the soil to which boron had been added, either as borax or colemanite, than in the control soil; but no evidence of a cumulative action in the soil was found.

The colemanite plots showed more total boric acid than the borax plots. This is not surprising, in view of the fact that more total boron was added to the colemanite than to the borax plots.

BORON AND PLANT INJURY

Nakamura (5) tested the effect of borax on barley grown in pot cultures. He found that amounts of borax equivalent to 0.001 per cent of boric acid were toxic and that amounts of borax equivalent to 0.0002 per cent of boric acid produced slight injury.

Agulhon (1) grew wheat in pot cultures with sand and nutrient media to which he added varying amounts of boric acid. He found that 0.005 per cent of boric acid killed the wheat plants, while 0.001 per cent had no toxic effect.

Voelcker (6) in experiments with pots holding 40 pounds of soil, determined that 0.005 to 0.1 per cent of boric acid (H_3BO_3) and borax ($Na_2B_4O_7$) prevented the germination of wheat. He found that 0.001 per cent of either compound was harmful, but amounts from 0.0005 to 0.001 per cent were beneficial, the effectiveness increasing with the decreased percentage of boron.

In the field tests conducted by the writers at Arlington, Va., the presence of 0.0088 per cent of boric acid (added as borax) in the upper 6 inches of soil was toxic to wheat, while 0.0022 per cent added as borax, or 0.0029 per cent as colemanite was nontoxic to wheat.

It is interesting to recall that the soil sample taken nine months after the addition of the 0.0088 per cent of boric acid as borax in 1914 contained soluble boron. The other soil samples for three years and samples from this plot the next two years showed no detectable amounts of soluble boron and no injury to the wheat. The results of the analyses for soluble boron in soils from Orlando, Fla., New Orleans, La., and Dallas, Tex., to which borax had been added showed the presence of considerable amounts of soluble boron in the soils from Orlando and New Orleans where the crops had been decidedly injured by the borax. The crops at Dallas showed no injury, and no soluble boron was detected in the soil.

In brief, there appears to be a direct connection between the presence of soluble boron in soil and injury to plant growth. There is apparently a gradual combination of the soluble boron added to soil either as a silicate or calcium borate. The rapidity with which soluble boron becomes insoluble varies with each individual soil or soil type and with climatic and other factors.

SUMMARY

In field tests at Arlington, Va., based on the yield of the manured control plot, borax reduced the yield of wheat (grain) 10 per cent in 1914 and 1915, while colemanite had little, if any, effect. The manured control gave the largest yields of grain in 1914 and 1915, and the unmanured controls the lowest yields.

In 1916 the yields from all four plots were low, and the proportion of straw to grain was higher than during the two previous years. In 1916 the borax plot gave the best yield.

During the three years there were seasonal variations involving a gradual decrease of fat and an increase of nitrogen in the grain and straw from all plots. During this period the moisture in the straw increased and that of the grain decreased.

More boron was absorbed by the plants from the borax than from the colemanite plots, although only minute amounts of boron were absorbed by any of the wheat plants. The 1916 samples of straw and grain contained more boron than the 1914 and 1915 samples. In all samples a relatively uniform distribution of boron in the straw and grain was found.

A yellowing of the young plants was observed the first year (1914) on the borax plot. This directly followed a heavy application of borax manure to the plot, and the sample of soil from this plot taken nine months later showed the presence of soluble boron. In no other soil sample was any soluble boron found. Apparently the added borax is gradually combined in an insoluble compound and so distributed that the upper 6 inches of soil show little total boron after three yearly additions of borax. There were no evidences of any cumulative action of boron in the soil. It was apparently the soluble boron, not the total boron, in the soil that produced injury to the wheat plants.

LITERATURE CITED

(1) AGULHON, H.
1910. RECHERCHES SUR LA PRÉSENCE ET LE RÔLE DU BORE CHEZ LES VÉGÉTAUX. 163 p., 6 pl. Paris.

(2) AMERICAN PUBLIC HEALTH ASSOCIATION.
1912. STANDARD METHODS FOR THE EXAMINATION OF WATER AND SEWAGE. 144 p. New York. Bibliography, p. 70–74, 137–140.

(3) COOK, F. C.
1916. BORON: ITS ABSORPTION AND DISTRIBUTION IN PLANTS AND ITS EFFECT ON GROWTH. *In* Jour. Agr. Research, v. 5, no. 19, p. 877–890. Literature cited, p. 889–890.

(4) FOLIN, Otto, and MCCALLUM, A. B.
1912. ON THE DETERMINATION OF AMMONIA IN URINE. *In* Jour. Biol. Chem., v. 11, no. 5, p. 523–525.

(5) NAKAMURA, M.
1903. CAN BORIC ACID IN HIGH DILUTION EXERT A STIMULANT ACTION ON PLANTS? *In* Bul. Col. Agr., Tokyo Imp. Univ., v. 5, no. 4, p. 509–512, pl. 28.

(6) VOELCKER, J. A.
1915. THE INFLUENCE OF BORON COMPOUNDS ON WHEAT AND BARLEY. *In* Jour. Roy. Agr. Soc. England, v. 76, p. 347–363, 10 pl.

ENERGY VALUES OF HOMINY FEED AND MAIZE MEAL FOR CATTLE

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INTRODUCTION

Hominy feed is a by-product of the milling of maize (*Zea mays*) for the production of hominy. In the winter of 1909–10 a series of 10 respiration calorimeter tests was carried out at the Institute of Animal Nutrition for the purpose of determining, by the methods outlined in a previous paper (2),[1] the net energy value of this by-product as compared with that of the maize from which it is manufactured. Some of the data obtained, together with earlier results on maize meal, were included with others in the general discussion of net energy values contained in the paper just referred to, but a review of these results and a more specific comparison of maize with its by-product, hominy feed, or hominy chop, including some more recent results on maize meal (3) seem desirable.

THE FEEDING STUFFS

As stated, hominy feed is a by-product of the manufacture of hominy or brewers' grits. In addition to their use as food, these products are used somewhat extensively by brewers and bakers. They are intended to consist substantially of the endosperm of the maize from which the hulls and germs have been completely separated. It is desired to reduce their percentage of fat to the minimum, and for this reason maize low in fat is preferred and special stress is laid upon the complete separation of the germ. White corn is used exclusively. It is first moistened to loosen the hull and then is passed through a machine called a "degerminator," which cracks the grains and is intended to remove the hulls and germs. The first separation, however, is incomplete, and from this point the material undergoes a process of gradual reduction and separation similar in its general outline to that used in the milling of wheat.

A comparison of the composition of our hominy feed,[2] as shown by analyses of two independent samples, with that of the hominy feed used

[1] Reference is made by number to "Literature cited," p. 613.

[2] Through the courtesy of the Miner-Hillard Milling Co., of Wilkes-Barre, Pa., we were able to obtain for experimental purposes a quantity of the freshly manufactured hominy feed and also of the maize from which it was made, and likewise to secure data as to the yield of the various products of the milling.

by Lindsey (6, 7) in the digestion experiments hereafter referred to, and with Henry and Morrison's average of the composition of 778 samples (5, p. 633), is contained in Table I, from which it appears that our hominy feed was of normal composition.

TABLE I.—*Percentage composition of hominy feed, water-free*

Constituent.	Our analyses.	Lindsey's analyses.		Henry and Morrison's average.
		1904 and 1905.	1907.	
Ash	2.75	3.38	2.78	2.9
Protein [a]	9.33	[b] 12.23	[b] 11.59	[b] 11.8
Nonprotein [c]	1.29			
Crude fiber	5.13	4.97	5.28	4.9
Nitrogen-free extract	72.65	69.43	71.54	71.5
Ether extract	8.85	9.99	8.81	8.9
	100.00	100.00	100.00	100.0
Total nitrogen	1.83	.....	.....	.....
Carbon	47.31	.....	.....	.....
Heat of combustion per kilogram, Calories	4,709	.....	.....	.....

[a] Protein N×6.0. [b] Total N×6.25. [c] Nonprotein N×4.7.

The composition of the maize meal employed in this experiment (designated as experiment 211) and of that used in other experiments here, and likewise Henry and Morrison's average of 5,335 analyses (5, p. 633), is shown in Table II.

TABLE II.—*Percentage composition of maize meal, water-free*

Constituent.	Our experiments.			Henry and Morrison's average.
	Experiment 179.	Experiment 211.	Experiment 220.	
Ash	1.37	1.62	1.40	1.47
Protein [a]	9.94	9.29	9.78	[c] 10.48
Nonprotein [b]	0.48	0.24	0.28	
Crude fiber	2.60	3.16	2.04	2.59
Nitrogen-free extract	81.38	80.64	82.17	81.18
Ether extract	4.23	5.05	4.33	4.28
	100.00	100.00	100.00	100.00
Total nitrogen	1.758	1.60	1.689	.....
Carbon	45.03	46.80	46.16	.....
Heat of combustion per kilogram, Calories	4,431	4,517	4,505	.....

[a] Protein N×6.0. [b] Nonprotein N×4.7. [c] Total N×6.25.

The hay used in our experiments was mixed clover and timothy. In view of the rather low percentage of protein in the concentrates, a legume hay would probly have been preferable, had one been available. The

average composition of eight independent samples of the hay was as shown in Table III.

TABLE III.—*Percentage composition of mixed hay, water-free*

Constituent.	Composition.
Ash	7.01
Protein [a]	9.62
Nonprotein [b]	1.29
Crude fiber	33.78
Nitrogen-free extract	46.00
Ether extract	2.30
	100.00
Heat of combustion per kilogram..Calories..	4,396

[a] Protein N×6.25. [b] Nonprotein N×4.7.

PARTITION OF INGREDIENTS OF MAIZE

From a bushel (56 pounds) of maize there are obtained about 38 pounds of hominy, or grits, and about 18 pounds of by-products, consisting of—

(a) The hulls of the grains, together with the tips, derived from the cob.....about 2 pounds.
(b) The germs.....about 9 pounds.
(c) The starch immediately surrounding the germ and tip, which is necessarily scoured off in the various processes of grinding and screening.....about 7 pounds

These three products ground together constitute hominy feed. The percentages of the various products, therefore, are approximately—

Hominy		67.9
Hulls and tips	3.5	
Germs	16.1	
Scourings	12.5	
		32.1
		100.0

Partial analyses of samples of the hulls and tips, the germs, and the hominy were also made, with the results shown in Table IV.

TABLE IV.—*Percentage composition of milling products*

Product.	Total dry matter.	In dry matter.		
		Ash.	Nitrogen.	Carbon.
Hominy	86.60	0.50	1.46	45.03
Hulls and tips	91.42	1.92	1.41	47.81
Germs	91.02	5.95	2.49	50.60

From the foregoing figures the partition of the ingredients and of the energy of 100 pounds of maize between the several products of the milling may be computed to have been as shown in Tables V and VI. The outstanding differences are the considerable proportion of the nitrogen and the large proportion of the ash of the maize found in the hominy feed.

TABLE V.—*Partition of ingredients of 100 kgm. of maize*

Constituent.	Dry matter.	Ash.	Nitrogen.	Carbon.	Energy.
	Kgm.	*Kgm.*	*Kgm.*	*Kgm.*	*Therms.*
In 3.5 kgm. of hulls and tips..	3.20	0.06	0.04	1.53	.....
In 16.1 kgm. of germs.....	14.65	.87	.36	7.41	.....
In 12.5 kgm. of scourings....	8.30	.16	.11	4.34	.....
In 32.1 kgm. of hominy feed..	26.15	1.09	.51	13.28	123.14
In 67.9 kgm. of hominy.....	58.80	.29	.86	26.48	*a* 260.58
In 100 kgm. of maize.....	84.95	1.38	1.37	39.76	383.72

a By difference.

TABLE VI.—*Percentage partition of each ingredient*

Constituent.	Dry matter.	Ash.	Nitrogen.	Carbon.	Energy.
Hulls and tips.....	3.77	4.35	2.92	3.85	.....
Germs.....	17.25	63.04	26.28	18.64	.....
Scourings.....	9.77	11.59	8.03	10.91	.....
Hominy feed.....	30.79	78.98	37.23	33.40	32.09
Grits.....	69.21	21.02	62.77	66.60	67.91
Maize.....	100.00	100.00	100.00	100.00	100.00

ANIMALS

The experiments were made upon two steers. It was not found practicable to make the comparison on the same animal, since the experiment had other objects, but the two steers were of like breed and very similar in type, steer D being a grade Hereford, 33 months old, and steer G a full-blood Hereford, 38 months old.

GENERAL PLAN

Each animal received three different amounts of hay in as many periods, and from the data thus obtained the energy values of the hay were computed. In two additional periods steer D received a mixed ration of equal parts of hominy feed and mixed hay, and steer G a mixed ration of 1 part mixed hay and 2 parts maize meal. One of these two rations in each case was intended to be approximately a maintenance ration, while the other was as heavy a ration as it was found practicable

to feed. The results upon the concentrates were computed upon the assumption of unchanged utilization of the hay as computed from the three periods on hay alone.

Each period comprised 21 days, of which 11 were regarded as preliminary, while the visible excreta were collected quantitatively for the remaining 10. The complete balance of matter and energy was determined with the respiration calorimeter on the eighteenth and nineteenth days of each period. A list of the periods and rations fed and of the average live weights of the animals is contained in Table VII.

TABLE VII.—*Periods, rations, and live weights of experimental animals*

Period No.	Preliminary feeding.	Excreta collected.	Rations.			Average live weights.
			Mixed hay.	Hominy feed.	Maize meal.	
	1909.		*Kgm.*	*Kgm.*	*Kgm.*	*Kgm.*
Steer D:						
Period 1	Dec. 19–29	Dec. 30, 1909–Jan. 8, 1910.	7.0	.....	.....	460
	1910.	1910.				
Period 2	Jan. 9–19	Jan. 20–29	2.0	2.0	.....	432
Transition feeding.	Jan. 30–Feb. 5	.....	.....	.....	.....	.....
Period 3	Feb. 6–16	Feb. 17–26	4.5	4.5	.....	470
Transition feeding.	Feb. 27–Mar. 5	.....	.....	.....	.....	.....
Period 4	Mar. 6–16	Mar. 17–26	4.0	.....	.....	455
Period 5	Mar. 27–Apr. 6	Apr. 7–16	2.0	.....	.....	428
Steer G:						
Period 1	Jan. 2–12	Jan. 13–22	7.0	.....	.....	389
Period 2	Jan. 23–Feb. 2	Feb. 3–12	.9	.....	1.8	358
Transition feeding.	Feb. 13–19	.....	.....	.....	.....	.....
Period 3	Feb. 20–Mar. 2	Mar. 3–12	2.7	.....	5.4	398
Transition feeding.	Mar. 13–19	.....	.....	.....	.....	.....
Period 4	Mar. 20–30	Mar. 31–Apr. 9	3.6	.....	.....	387
Period 5	Apr. 10–20	Apr. 21–30	1.8	.....	.....	364

PERCENTAGE DIGESTIBILITY

The digestibility of the total rations and that of the grain as computed on the assumption that the hay consumed with it had the digestibility shown by the true average of the periods on hay alone was as shown in Table VIII.

TABLE VIII.—*Percentage digestibility of rations and of grain*

Animal and constituent.	Hay.				Mixed hay and grain.		Computed digestibility of grain.	
	Period 1.	Period 4.	Period 5.	Average.	Period 2.	Period 3.	Period 2.	Period 3.
Steer D (hominy feed):								
Dry matter	55.96	60.58	58.23	57.72	72.71	72.42	87.56	86.98
Ash	40.79	34.72	37.77	38.58	30.79	43.42	11.09	56.38
Organic matter	57.09	62.32	59.72	59.10	74.89	73.97	89.83	87.98
Protein	44.38	59.29	58.50	48.10	55.73	59.01	63.04	71.64
Crude fiber	52.09	59.31	55.21	54.76	61.09	54.92	101.94	55.94
Nitrogen-free extract	62.96	66.57	65.79	64.52	81.40	80.93	91.97	91.10
Ether extract	56.38	56.90	56.94	56.65	88.50	87.27	96.47	95.36
Total nitrogen	49.10	53.35	49.96	50.54	58.54	64.06	66.25	77.98
Carbon	52.98	58.52	56.32	55.18	72.65	71.91	89.33	88.03
Energy	52.80	58.17	55.43	54.84	72.35	71.60	88.52	87.17
Steer G (maize meal):								
Dry matter	59.23	60.06	59.02	59.44	80.72	72.73	91.63	79.55
Ash	51.44	37.05	34.25	45.13	27.23	36.22	—11.90	15.89
Organic matter	60.54	61.60	60.82	60.89	82.62	74.06	93.16	80.45
Protein	48.56	50.72	37.27	47.76	63.22	55.57	71.06	59.95
Crude fiber	56.91	59.36	57.52	57.72	65.13	51.15	105.80	14.92
Nitrogen-free extract	64.02	66.26	66.02	64.98	88.90	80.90	95.91	85.54
Ether extract	58.35	55.35	62.09	58.09	85.13	80.15	90.87	85.53
Total nitrogen	52.53	49.73	50.34	51.41	62.71	56.32	68.98	59.22
Carbon	57.21	57.61	57.35	57.34	80.61	72.37	92.35	79.82
Energy	56.61	57.24	56.32	56.75	79.98	71.56	91.55	78.96

The average percentage digestibility of the hay, as computed from the aggregate feed and excreta of the three periods, did not differ as between the two animals to a greater extent than is often the case. The differences as regards dry matter, organic matter, and energy are about 2 per cent, for nitrogen about 1 per cent, for crude fiber about 3 per cent, and for the remaining ingredients less than 1 per cent.

The heavier hay and grain rations of period 3 as compared with the lighter ones of period 2 show a slight decrease of digestibility in the case of steer D (on hominy feed), and a decided decrease with steer G (on maize meal). In the latter case it is to be noted that the difference in the quantity consumed was also greater than with steer D and that the ratio of grain to hay was also greater.

METABOLIZABLE ENERGY

The data obtained regarding the amount of chemical energy escaping in feces, urine, and methane, and the metabolizable energy remaining have already been published (2), but the principal results are repeated in Table IX for convenience.

TABLE IX.—*Losses of chemical energy—metabolizable energy*

Feed, animal, and period.	Energy per kilogram of dry matter.					Metabolizable energy per kilogram of digestible organic matter.	Percentage losses.			Percentage metabolizable.
	Total.	Losses.			Metabolizable.		In feces.	In urine.	In methane.	
		In feces.	In urine.	In methane.						
	Calories.	*Calories.*	*Calories.*	*Calories.*	*Calories.*	*Calories.*				
Hay:										
Steer D, period 1	4,400	2,077	209	285	1,829	3,442	47.20	4.75	6.49	41.56
Steer D, period 4	4,391	1,837	234	332	1,990	3,406	41.83	5.33	7.54	45.30
Steer D, period 5	4,390	1,956	255	345	1,834	3,294	44.57	5.80	7.85	41.78
Steer G, period 1	4,393	1,906	208	300	1,979	3,463	43.39	4.75	6.82	45.04
Steer G, period 4	4,391	1,878	220	319	1,974	3,420	42.76	5.00	7.27	44.97
Steer G, period 5	4,390	1,917	238	358	1,877	3,313	43.68	5.41	8.15	42.76
Average	4,393	1,929	227	323	1,914	3,390	43.92	5.17	7.35	43.56
Hay and hominy feed:										
Steer D, period 2	4,560	1,261	209	403	2,687	3,775	27.65	4.58	8.84	58.93
Steer D, period 3	4,553	1,293	196	340	2,724	3,879	28.40	4.30	7.47	59.83
Average	4,557	1,277	203	371	2,706	3,827	28.02	4.44	8.15	59.39
Hay and maize meal:										
Steer G, period 2	4,483	897	189	443	2,954	3,701	20.00	4.22	9.88	65.90
Steer G, period 3	4,468	1,271	156	352	2,689	3,763	28.45	3.49	7.88	60.18
Average	4,476	1,084	173	398	2,821	3.732	24.22	3.87	8.89	63.02
Hominy feed (computed):										
Steer D, period 2	4,720	542	195	496	3,487	3,993	11.48	4.13	10.50	73.89
Steer D, period 3	4,698	603	167	371	3,557	4,156	12.83	3.56	7.90	75.71
Average	4,709	573	181	433	3,522	4,075	12.15	3.84	9.20	74.81
Maize meal (computed):										
Steer G, period 2	4,526	382	175	509	3,460	3,776	8.45	3.87	11.25	76.43
Steer G, period 3	4,508	948	125	372	3,063	3,869	21.04	2.78	8.25	67.93
Average	4,517	665	150	441	3,261	3,822	14.74	3.32	9.75	72.19

With steer D the heavier ration of period 3 as compared with period 2 resulted in a slightly greater loss in the feces, which, however, was slightly more than offset by lessened losses in urine and methane, so that the percentage metabolizable in the total ration was practically the same. With steer G, on the contrary, the much heavier ration of period 3 caused a marked falling off in digestibility which was only partially compensated by smaller losses in the urine and methane, so that the percentage metabolizable was distinctly less.

HEAT PRODUCTION

The heat production as measured by the respiration calorimeter compared with that computed in the ordinary manner from the balance of carbon and nitrogen is shown in Table X.

TABLE X.—*Observed and computed daily heat production*

Animal and period.	Observed.	Computed.	Difference.	Computed ÷ observed.
Steer D:	*Calories.*	*Calories.*	*Calories.*	*Per cent.*
Period 1 First day	11,276	11,951	675	106.0
Period 1 Second day	11,817	12,327	510	104.0
Period 2 First day	9,411	9,635	224	102.4
Period 2 Second day	9,782	9,992	210	102.1
Period 3 First day	13,845	13,593	252	98.2
Period 3 Second day	14,030	14,038	8	100.1
Period 4 First day	9,301	9,257	44	99.5
Period 4 Second day	9,092	9,198	106	101.2
Period 5 First day	7,899	7,940	41	100.5
Period 5 Second day	8,006	8,082	76	100.9
Steer G:				
Period 1 First day	11,669	11,601	68	99.4
Period 1 Second day	11,752	11,683	69	99.4
Period 2 First day	8,176	8,185	9	100.1
Period 2 Second day	8,218	8,275	57	100.7
Period 3 First day	13,307	12,829	478	96.4
Period 3 Second day	13,274	12,786	488	96.3
Period 4 First day	9,068	9,080	12	100.1
Period 4 Second day	8,806	8,806	0	100.0
Period 5 First day	6,938	6,786	152	97.8
Period 5 Second day	6,827	7,004	177	102.6

STANDING AND LYING

Standing and lying have been found to exert such an influence on the heat production of cattle that, in order to make comparisons, the observed results must be corrected to a uniform proportion of time standing and lying. The total heat production of each day of the 2-day periods has therefore been corrected to 12 hours' standing and 12 hours' lying in the manner described on page 454 of the paper already referred to (2) and the two days averaged. The distribution of this corrected heat production has also been computed by the method explained on page 468 of the same publication. The results of these computations are recorded in Table XI.

TABLE XI.—*Heat production corrected to 12 hours' standing*

Animal and period.	Dry matter eaten.		Corrected heat production.			Analysis of heat production.			
	Hay.	Grain.	First day.	Second day.	48-hour mean.	Standing 12 hours.	Rising and lying down.	Methane fermentation.	Remainder.
Steer D:	*Grams.*	*Grams.*	*Calories.*	*Calories.*	*Calories.*	*Calories.*	*Calories.*	*Calories.*	*Calories.*
Period 1	6,204	.....	11,775	12,995	12,359	1,679	79	805	9,796
Period 2	1,747	1,764	9,782	10,126	9,947	1,695	71	643	7,538
Period 3	3,910	3,949	14,877	15,040	14,936	1,850	102	1,216	11,768
Period 4	3,498	.....	9,481	9,680	9,625	1,498	76	527	7,524
Period 5	1,786	.....	8,291	8,259	8,258	1,497	57	282	6,422
Steer G:									
Period 1	6,092	.....	12,211	11,971	12,098	1,802	80	830	9,386
Period 2	790	1,542	8,678	8,362	8,470	1,505	74	470	6,421
Period 3	2,383	4,644	14,510	14,467	14,561	2,852	68	1,126	10,515
Period 4	3,149	.....	9,843	9,242	9,568	1,958	75	457	7,078
Period 5	1,608	.....	7,811	7,178	7,477	1,382	62	261	5,772

ENERGY EXPENDITURE CONSEQUENT ON FEED CONSUMPTION

It is a familiar fact that the consumption of feed tends to stimulate the metabolism of an animal, as is manifested by the increased amount of heat produced. The energy thus expended, as well as the chemical energy escaping in the excreta, must be deducted from the gross energy of a feeding stuff to obtain its net energy value. In this experiment the losses of energy in heat production per kilogram of dry matter, computed as in previous papers, are recorded in Table XII.

TABLE XII.—*Increment of heat production per kilogram of dry matter*

Feedstuff.	Animal, No.	Periods compared.	Total increment per kilogram.	Analysis of increment.			
				Standing 12 hours.	Rising and lying down.	Methane fermentation.	Remainder.
			Calories.	*Calories.*	*Calories.*	*Calories.*	*Calories.*
Mixed hay	D	1 and 5	928	41	5	118	764
Do	G	1 and 5	1,031	94	4	137	806
Average			980	67	5	123	785
Mixed hay and hominy feed	D	2 and 3	1,147	36	7	132	972
Mixed hay and maize meal	G	2 and 3	1,297	287	−1	140	871
Computed for hominy feed	D	2 and 3	1,365	30	9	146	1,180
Computed for maize meal	G	2 and 3	1,434	386	−4	146	906

One kgm. of maize dry matter appears to have caused a somewhat greater increase (about 5 per cent) in heat production than the same amount of hominy feed. A marked difference is manifested in the proportion of the increase due to standing, while the heat evolved by fermentation is substantially equal, and the direct stimulus to the metabolism ("remainder") is less with maize. The total difference is probably not very significant.

NET ENERGY VALUES

By subtracting from the gross energy of the hominy feed and maize meal, respectively, the losses of chemical energy in the feces, urine, and methane, as shown in Table IX, and the energy expenditure consequent upon its consumption as measured by the increment of heat production shown in Table XII, the following net energy values for the two feeding stuffs may be computed. Later investigations on maize meal (3), however, led to the conclusion that the figure obtained in this experiment for the heat expenditure in feed consumption was too high, and that 1,289 Calories per kilogram of dry matter was more nearly correct. The results in Table XIII are computed, using both factors.

TABLE XIII.—*Net energy values per kilogram of dry matter*

Feedstuff.	Gross energy.	Losses in excreta.	Expended in feed consumption.	Net energy value.
	Calories.	*Calories.*	*Calories.*	*Calories.*
Hominy feed	4,709	1,187	1,365	2,157
Maize meal	4,517	1,256	1,434	1,827
Maize meal, corrected result	4,517	1,256	1,289	1,972

COMPARISON WITH OTHER RESULTS

The results of this experiment indicate a distinct, although not great, superiority per kilogram of the hominy feed over the maize meal from which it was made. Before generalizing this conclusion it is obviously desirable to make such comparisons as are possible with results of other experiments.

AVERAGE RESULTS ON MAIZE MEAL

Additional determinations on the influence of maize meal upon the heat production, designated as experiments 179 and 220, have been reported from this Institute, and the results of 12 determinations of its digestibility have been averaged by Henry and Morrison (5). As Table II shows, the maize meal used in the trials just described did not differ materially in composition from that used in our other experiments nor from the composition shown by Henry and Morrison's average. The percentage digestibility of the ingredients of the samples of maize meal used in our several experiments (including the results already reported in Table VIII) is shown in Table XIV.

TABLE XIV.—*Percentage digestibility of maize meal*

Constituent.	Experiment 179.		Experiment 211.		Experiment 220.		
	Period 3.	Period 4.	Period 2.	Period 3.	Period 3.	Period 4.	Period 5.
Dry matter	64.91	76.23	91.63	79.55	89.78	81.54	90.63
Organic matter	66.26	77.68	93.16	80.45	90.15	82.37	91.55
Total nitrogen	63.68	61.58	68.98	59.22	69.68	59.21	71.77
True protein	57.05	58.01	71.06	59.95	74.74	65.46	76.34
Crude fiber	44.79	49.05	.....	14.92	76.27	17.42	8.68
Nitrogen-free extract	77.75	88.20	95.91	85.54	93.19	86.61	95.95
Ether extract	74.71	83.89	90.87	85.53	85.52	83.96	90.68
Energy	63.16	74.93	91.55	78.96	88.29	80.40	89.12

The results obtained in experiment 179, period 3, appear to have been abnormally low. The average of the 6 others, compared with Henry and Morrison's average of 12 experiments, is as follows (Table XV):

TABLE XV.—*Average percentage digestibility of maize meal*

Constituent.	Our experiments.	Henry and Morrison's average.
Dry matter	84.89	90
Organic matter	85.89	.....
Total nitrogen	65.07	74
True protein	67.57	.....
Crude fiber	27.72	57
Nitrogen-free extract	90.90	94
Ether extract	86.74	93
Energy	83.88	.....

Our averages are slightly lower than Henry and Morrison's. The latter did not include in their compilation experiments in which the nutritive ratio of the total ration was 1 to 12 or wider.[1] In all but one of our six experiments the nutritive ratio approached or passed 1 to 12, and this may account for the slightly lower digestibility. On the other hand, the lower digestibility in such cases appears to be due to a considerable extent to lessened fermentation of the carbohydrates and a correspondingly decreased loss of energy in methane, so that, as the writers have pointed out, a certain degree of compensation occurs as to the energy values and particularly as to the metabolizable energy per unit of digestible organic matter (2, p. 446, 451). It appears probable, therefore, that the factors for the latter quantity obtained in our experiments may be applied safely to other experiments also.

The metabolizable energy of maize meal in our experiments, computed as in Table IX (omitting experiment 179, period 3), was as shown in Table XVI. Henry and Morrison's results afford no data for a comparison of this sort.

TABLE XVI.—*Metabolizable energy of maize meal*

Experiment No.	Per kilogram dry matter.	Per kilogram digestible organic matter.
	Calories.	*Calories.*
Experiment 179, Period 4	3,392	3,716
Experiment 211, Period 2	3,460	3,776
Experiment 211, Period 3	3,063	3,869
Experiment 220, Period 3	3,334	3,753
Experiment 220, Period 4	3,129	3,851
Experiment 220, Period 5	3,200	3,543
Average	3,263	3,751

[1] Private communication.

It would appear that the factor 3.9 therms per kilogram of digestible organic matter proposed by the writers (2, p. 453) for concentrates containing less than 5 per cent of fat is somewhat high for maize meal and that 3.8 would be more nearly correct. Applying the latter factor to Henry and Morrison's averages for the digestible nutrients, and using the average result for the heat increment per kilogram of dry matter which was reported in a previous paper—viz, 1.289 therms per kilogram dry matter—gives the results in Table XVII.

TABLE XVII.—*Energy values of average maize meal per kilogram dry matter*

	Calories.
Metabolizable energy	3,402
Energy expended in feed consumption	1,289
Net energy value	2,113

AVERAGE RESULTS ON HOMINY FEED

The composition of our sample, as shown by Table I, corresponded substantially to Henry and Morrison's average of 778 samples of high-grade hominy feed. No other determinations on the influence of hominy feed upon the heat production of an animal have been reported, but the average of nine determinations by Lindsey (6, 7) of its digestibility by sheep is given by Henry and Morrison (5, p. 647).

A reference to the original shows that the "English hay" used in eight out of the nine experiments was notably lower in protein than the mixed hay used in our experiments. Whether or not as a consequence of this lack of protein, three experiments out of the nine showed coefficients distinctly lower than the remainder—viz, for dry matter 71 per cent, 75 per cent, and 78 per cent. If these three apparently exceptional results are omitted, the average of the remaining six corresponds very well with our data, as Table XVIII shows.

TABLE XVIII.—*Percentage digestibility of hominy feed*

Constituent.	Lindsey's results.		Our results (two experiments).	Average of Lindsey's six and our two experiments.
	Nine experiments.	Six experiments.		
Dry matter	82.94	87.16	87.27	87.19
Organic matter	.....	.....	88.91	88.91
Total nitrogen	65.53	68.59	72.12	69.47
True protein	.....	.....	67.34	67.34
Crude fiber	75.60	87.87	78.94	85.64
Nitrogen-free extract	89.61	92.18	91.54	92.82
Ether extract	91.16	90.00	95.92	91.48

Regarding the figures of the last column of Table XVIII as representing the average digestibility of hominy feed, we may compute from the

average composition as shown in Henry and Morrison's compilation (Table I) the digestible organic matter. Multiplying the latter by the factor 4.075 Calories per gram obtained in our experiments, we may compute the energy values of average hominy feed to be as follows (Table XIX):

TABLE XIX.—*Energy values of average hominy feed per kilogram of dry matter*

	Calories.
Metabolizable energy	3,542
Energy expended in feed consumption	1,365
Net energy value	2,177

The results of the foregoing comparisons agree with those of Experiment 211 in giving a somewhat higher net energy value for hominy feed than for maize meal, although the difference is small in both cases, and in the average results hardly significant (Table XX).

TABLE XX.—*Average net energy values per kilogram of dry matter*

Feedstuff.	From experiment 211.	Computed from average results.
	Calories.	*Calories.*
Maize meal	1,972	2,113
Hominy feed	2,157	2,177

From the foregoing results and from the data contained in Table V it may be computed that the partition of the net energy of maize between the hominy and the total by-products included in the hominy feed is as follows:

TABLE XXI.—*Percentage partition of net energy of maize*

Feedstuff.	Computed from experiment 211.	Computed from average results.
In hominy feed	33.67	31.72
In hominy	66.33	68.28
In maize	100.00	100.00

CORRECTION OF EARLIER TABLES

In three earlier publications (1, 4, 8) there has appeared a table of net energy values of feeding stuffs for cattle computed in the manner proposed by the writers (2, p. 486) from Henry and Morrison's figures for digestible nutrients (5, p. 653). The foregoing results indicate that the averages given in that table for maize and hominy feed require some correction.

In the case of maize the metabolizable energy was estimated at 3.9 Calories per gram of digestible organic matter as in the case of other similar concentrates. As shown above, the actual average is about 3.75 Calories per gram—that is, lower than that of other concentrates which have been experimented with—so that the tabulated results are somewhat too high.

In the case of the hominy feed an error was made, we believe, in the other direction by using too low figures for the average digestibility of this material. On the basis of the results here discussed, we submit the following corrections (Table XXII) for the table referred to:

TABLE XXII.—*Net energy values per 100 pounds (with average water content) for cattle*

Feedstuff.	As published.	Corrected.
	Therms.	*Therms.*
Maize, dent	89.16	85.50
Maize, flint	87.50	84.00
Maize meal	88.75	85.20
Hominy feed	81.31	88.78

SUMMARY

A comparison is reported of the metabolizable energy and of the net energy value of hominy feed as determined in an experiment on a grade Hereford steer with the corresponding values for maize meal ground from the same grain, as determined in a parallel experiment on a full-blood Hereford of about the same age. Data are also reported as to the partition of the ingredients and energy of maize meal among the products of its milling for the production of hominy.

An increase in the amount of the mixed ration of hay and hominy feed consumed resulted in a slightly decreased digestibility, while a greater increase in the amount of mixed hay and maize meal consumed caused a considerable decrease in digestibility.

The average percentage losses of energy in the excreta were greater with maize meal than with hominy feed, chiefly on account of the somewhat lower digestibility of the former, notably in the heavier ration.

The metabolizable energy per kilogram of dry matter and per kilogram of digestible organic matter was greater for the hominy feed than for the maize meal, the difference being due to the higher gross energy and smaller losses in the former case.

The increment of heat production by the animal per kilogram of dry matter consumed was slightly less for the hominy feed than for the maize meal but slightly greater than the average of all experiments on the latter material.

The net energy value of the hominy feed in this experiment was distinctly greater than that of the maize meal. A computation of the net

energy values based on the average composition and digestibility of the two materials reduced this difference to an insignificant amount.

Corrections are reported for the net energy values of hominy feed and maize meal contained in earlier tables.

LITERATURE CITED

(1) ARMSBY, H. P.
1916. THE USE OF ENERGY VALUES IN THE COMPUTATION OF RATIONS FOR FARM ANIMALS. U. S. Dept. Agr. Bul. 459, 29 p.
A revision of Farmers' Bul. 346.

(2) ——— and FRIES, J. A.
1915. NET ENERGY VALUES OF FEEDING STUFFS FOR CATTLE. *In* Jour. Agr. Research, v. 3, no. 6, p. 435–491, 2 fig. Literature cited, p. 489–491.

(3) ——— ——— and BRAMAN, W. W.
1916. ENERGY VALUES OF RED-CLOVER HAY AND MAIZE MEAL. *In* Jour. Agr. Research, v. 7, no. 9, p. 379–387.

(4) ——— and PUTNEY, F. S.
1916. NET ENERGY VALUES OF AMERICAN FEEDING STUFFS. *In* Penn. Agr. Exp. Sta. Bul. 142, p. 15–20.

(5) HENRY, W. A., and MORRISON, F. B.
1915. FEEDS AND FEEDING . . . ed. 15, 691 p. Madison, Wis.

(6) LINDSEY, J. B.
1904–05. DIGESTION EXPERIMENTS WITH SHEEP. *In* Mass. Agr. Exp. Sta. 16th Ann. Rpt. [1902/03], p. 63–79, 1904; 17th Ann. Rpt. [1903/04], p. 45–77, 1905.

(7) ——— HOLLAND, E. B., and SMITH, P. H.
1907. THE DIGESTIBILITY OF CATTLE FOODS. *In* Mass. Agr. Exp. Sta. 19th Ann. Rpt. [1905/06], p. 96–156.

(8) PUTNEY, F. S., and ARMSBY, H. P.
1916. COMPUTATION OF DAIRY RATIONS. Penn. Agr. Exp. Sta. Bul. 143, 24 p.

FURTHER STUDIES OF THE MOSAIC DISEASE OF TOBACCO

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SUSCEPTIBILITY OF PLANTS TO INFECTION THROUGH THE TRICHOMES

The virus of the mosaic disease of tobacco (*Nicotiana tabacum*) is readily inoculated into the tissues of healthy plants. The disease may be easily communicated by means of a needle through the roots, the stems, or the leaves. It is interesting to note that inoculations are also successful when the virus is introduced into susceptible plants through the trichomes of the leaves alone. Experiments have shown that a very high percentage of infection may be obtained when the virus is painted or rubbed lightly upon the leaves with a soft brush.[1]

The following experiments (Table I) make this fact plain. Young plants of the Connecticut Broadleaf variety growing in 3-inch pots were used in all tests.

TABLE I.—*Experiments showing infectivity of the virus when inoculated into the trichomes of leaves of tobacco plants*

Number of plants.	Date of inoculation.	Treatment.	Results.
	1915.		
10.....	Aug. 23	Virus painted on several leaves with a camel's-hair brush.	First symptom August 28; 10 mosaic September 3.
10 (control).....	....do.....	Healthy sap painted on one leaf with a camel's-hair brush.	All healthy September 3.
10.....	Aug. 27	Virus painted lightly on the trichomes of one leaf only with a camel's-hair brush.	First symptom September 1; 10 mosaic September 7.
10.....	....do.....	Tips of trichomes on the smallest, inmost leaf pinched and bruised with forceps moistened with the virus of mosaic. The leaf surface was not touched.	First symptom September 1; 5 mosaic September 7.

[1] Clinton has observed that the mosaic disease of tobacco is readily communicable to healthy plants by rubbing the virus upon the leaves. (CLINTON, C. D. CHLOROSIS OF PLANTS WITH SPECIAL REFERENCE TO CALICO OF TOBACCO. *In* Conn. Agr. Exp. Sta. Rpt. 1914, p. 357-424, pl. 25-32. 1915.)

Journal of Agricultural Research,
Washington, D. C.
ju

Vol. X, No. 12
Sept. 17, 1917
Key No. G—120

TABLE I.—*Experiments showing infectivity of the virus when inoculated into the trichomes of leaves of tobacco plants*—Continued

Number of plants.	Date of inoculation.	Treatment.	Remarks.
	1915.		
10 (control)..	Aug. 27	Tips of the trichomes of the youngest leaves pinched and crushed with forceps dipped in healthy sap and tap water.	All healthy September 7.
10.....	Aug. 28	Fresh virus rubbed lightly on the trichomes of two of the youngest leaves with a brush.	First symptom September 2; 10 mosaic September 7.
10.....	...do.....	Trichomes pinched and bruised with forceps moistened with virus of mosaic.	10 plants mosaic September 7.
10 (control)..	...do.....	Trichomes pinched and bruised with sterilized forceps dipped in healthy sap and tap water.	All healthy September 7.
10.....	Aug. 29	Fresh virus punctured into several leaves with a needle.	9 mosaic September 7.
10.....	...do.....	Trichomes of the smallest leaves pinched and crushed with forceps dipped in the virus of mosaic.	6 mosaic September 7.
10.....	...do.....	.....do.....	8 mosaic September 7.
10 (control)..	...do.....	Tap water and fresh healthy sap inoculated into the leaves with a needle.	All healthy September 7.
10.....	Aug. 30	Tips of the trichomes of the smallest, inmost leaves cut with small scissors and fresh virus carefully introduced upon the cut surface.	First symptom September 1; 9 mosaic September 7.
10.....	...do.....	.....do.....	7 mosaic September 7.
10.....	...do.....	.....do.....	9 mosaic September 7.
10 (control)..	...do.....	Tap water and healthy sap painted upon the trichomes of the leaves.	All healthy September 7.

It is evident that the infective principle very readily enters a plant through the trichomes, if these are broken or bruised. The readiness with which plants may be affected in this manner accounts for the high percentage of infection obtained in the touching and handling experiments of earlier investigators working with the mosaic disease of tobacco.

The following experiments indicate that the infective principle of the disease may also be extracted from the trichomes of mosaic plants. On October 23, 1915, the trichomes of the youngest leaves of a mosaic plant were carefully cut with small scissors previously sterilized by boiling. The trichomes of the youngest leaves of a healthy plant were then cut with the same scissors. In this process of cutting the trichomes are more or less bruised and macerated. This operation was repeated, with healthy and mosaic plants alternately, until 10 healthy plants were treated in this manner. Eight of the healthy plants so treated were mosaic on November 3, 1915. Ten control plants treated in the

same manner—that is, by cutting the trichomes of healthy plants with sterilized scissors—remained healthy. The preceding test was again repeated with the trichomes of mosaic plants on October 30, 1915. Of the 10 plants thus treated, 5 were mosaic on November 27, 1915. All controls remained healthy.

EFFECT OF SPRAYING AND DROPPING THE VIRUS UPON THE LEAVES OF TOBACCO PLANTS

All experiments indicate that the infective principle of the mosaic disease of tobacco does not readily invade uninjured trichomes or leaf tissues. Although infection sometimes follows when the virus is merely sprayed upon the leaves with an atomizer, or dropped carefully upon the surface at one or two points, this appears to be a very uncertain method of producing infection in healthy plants. If, on the other hand, the virus is sprayed upon the leaves and subsequently rubbed in, infection readily follows, probably from the fact that the trichomes are more or less injured (Table II).

TABLE II.—*Effect of spraying and dropping the virus upon the leaves of 10 Connecticut Broadleaf tobacco plants*

Treatment.	Date inoculated.	Results.
	1915.	
Fresh virus sprayed upon leaves with an atomizer	Sept. 15	4 mosaic.
Virus rubbed upon trichomes	...do.....	10 mosaic.
Control. Inoculated with tap water	...do.....	All healthy.
Fresh virus sprayed upon leaves till moist	Dec. 28	Do.
Fresh virus sprayed upon the leaves as in the preceding test and the leaf surfaces then rubbed with a stiff brush.	...do.....	8 mosaic.
Leaf surface rubbed with cut end of petiole of a green mosaic leaf.	...do.....	10 mosaic.
One drop of fresh virus dropped carefully on one leaf	...do.....	All healthy.
One drop of fresh virus dropped on one leaf as in the preceding test and rubbed in at this point.	...do.....	1 mosaic.
Control. Leaf surfaces rubbed with cut end of petiole of a healthy leaf.	...do.....	All healthy.

EFFECT OF ONE AS COMPARED WITH SEVERAL INOCULATIONS

Various experiments have shown that infection is more likely to follow if the virus is inoculated into the plants at more than one point. As shown in Table III, the percentage of infection is highest in those tests where many inoculations have been made.

It is rather interesting to note that, even though the virus be introduced into each plant of a series at many points, it is not unusual for some plants to escape infection.

TABLE III.—*Effect of one inoculation as compared with several inoculations in young plants. Inoculations made with a needle, introducing the virus into each puncture*

Number of plants inoculated.	Number of inoculations.	Distribution of inoculations.	Date inoculated.	Result.	Percentage mosaic.
			1915.		
77 Maryland Mammoth..	1	One in one leaf.....	Jan. 13	5 mosaic....	6
76 Maryland Mammoth..	2	One in each of two leaves.....	...do....	22 mosaic...	28
54 Maryland Mammoth..	1	One in one leaf.....	...do....	6 mosaic....	11
44 Maryland Mammoth..	2	One in each of two leaves.....	...do....	25 mosaic...	56
103 Maryland Mammoth.	1	One in one leaf.....	Jan. 9	13 mosaic...	12
109 Maryland Mammoth.	3	Two in one leaf; one in a second leaf.	...do....	71 mosaic...	65
41 (first-generation hybrid).	1	One in one leaf.....	...do....	3 mosaic....	7
54 Maryland Mammoth..	Many.	In all the leaves.....	...do....	45 mosaic...	83
50 Connecticut Broadleaf.	1	In middle of one leaf near midrib..	May 8	7 mosaic....	14
Do.....	Many.	In all the leaves.....	...do....	50 mosaic...	100
10 Connecticut Broadleaf.	1	One in middle of one leaf near midrib.	Aug. 24	All healthy..	.....
Do.....	2	Two in one leaf, one on each side midrib near middle.	...do....	.....do.....	.....
Do.....	3	Two in one leaf, one in second at middle near midrib.	...do....	1 mosaic....	10
Do.....	4	Two in each of two leaves near middle, and one on each side midrib.	...do....	.....do.....	10
Do.....	Many.	In all the leaves.....	...do....	7 mosaic....	70
Do.....	Many.	With tap water in all the leaves (control).	...do....	All healthy..	.....
Do.....	1	One in one leaf.....	Dec. 21	3 mosaic....	30
Do.....	2	One in each of two leaves.....	...do....	5 mosaic....	50
Do.....	3	One in each of three leaves.....	...do....	3 mosaic....	30
Do.....	4	One in each of four leaves.....	...do....	8 mosaic....	80
Do.....	5	One in each of three leaves; two in a fourth.	...do....	.....do.....	80
Do.....	6	Two in each of three leaves.....	...do....	9 mosaic....	90
Do.....	7	Two in each of three leaves; one in a fourth.	...do....	8 mosaic....	80
Do.....	8	Two in each of four leaves.....	...do....	6 mosaic....	60
Do.....	10	Two in each of four leaves; one in a fifth.	...do....	9 mosaic....	90
			1916.		
Do.....	1	One in one leaf.....	Jan. 31	All healthy..	.....
Do.....	2	One in each of two leaves.....	...do....	3 mosaic....	30
Do.....	3	Two in one leaf; one in a second leaf.	...do....	4 mosaic....	40
Do.....	4	Two in each of two leaves.....	...do....	5 mosaic....	50
Do.....	5	Three in two leaf; two in a second leaf.	...do....	6 mosaic....	60
Do.....	6	Two in each of three leaves.....	...do....	5 mosaic....	50
Do.....	8	Four in each of two leaves.....	...do....	.....do.....	50
Do.....	10	Five in one leaf; three in a second leaf and two in a third leaf.	...do....	10 mosaic...	100
Do.....	12	In all the leaves.....	...do....	9 mosaic....	90
Do.....	15	.....do.....	...do....	10 mosaic...	100
Do.....	20	.....do.....	...do....	8 mosaic....	80
Do.....	20	With tap water in all the leaves....	...do....	All healthy..	.....
Do.....	Many.	.... do.....	...do....	.....do.....	.....

THE QUESTION OF RESISTANCE TO MOSAIC DISEASE IN TOBACCO PLANTS

In a series of plants, even though a large number of inoculations may be made in the leaves of each plant as nearly as possible in the same manner, a few plants may escape infection and remain free from the disease until maturity.

Experiments have been carried out to determine whether such plants produce progenies which are more or less resistant to the disease. In one series 50 young Connecticut Broadleaf plants were inoculated at one

point in a single leaf. Fifty similar plants were also inoculated at 20 points in several of the largest growing leaves. A very small percentage of the plants receiving a single inoculation became infected with the mosaic disease. In the series receiving 20 inoculations a few plants failed to become infected with the disease. Two plants which became infected from a single inoculation and five plants which remained free from the disease until maturity after 20 inoculations were allowed to produce seed. Seed of each plant was sowed separately, and a series of young plants from each mother was inoculated once in a single leaf. In these tests progenies of the mother plants which escaped infection after 20 inoculations did not give any evidence of greater immunity to the mosaic disease than progenies from the mother plants which became diseased from a single inoculation. It is difficult to explain why some plants fail to become infected with the virus even after many thorough needle inoculations have been made. Other experiments have shown that even these apparently resistant plants may readily succumb to later inoculations, for if they are more resistant than others, it seems to be a resistance of a more or less temporary nature. Even in the field, where the mosaic disease is very widespread, a few plants may be found which escape the disease. Whether or not such plants have escaped infection, or are actually more resistant than others, can not be determined until experimental inoculations have been made. Investigations dealing with large numbers of plants along this line would perhaps throw light on the question of relative resistance of different individuals.

Different individuals of the same strain may show different degrees of expression of the disease. One plant may show the mottled phase particularly well developed. A sister plant may show extreme stunting and the development of depauperate leaves and blossoms. These differences appear to depend upon constitutional differences in individual plants rather than upon differences in the degree of virulence of the virus. Inoculation experiments indicate that the virus extracted from the slightly mottled plant produces essentially the same type of disease in young plants as is obtained from the virus of plants showing the most extreme stunting and malformation of the leaves. Individual differences in the expression of the disease in the same strain are probably analagous to those differences observed when plants of different genera of the solanaceous family become infected with the mosaic disease.

Certain characteristics associated with the expression of the mosaic disease of tobacco are more or less dependent upon unfavorable conditions of growth. Plants showing the mottled phase in the field when transplanted to the greenhouse often develop depauperate leaves and blossoms. Although the blossoms may be beautifully mottled, it is very rare to find catacorolla showing in field plants, however badly they may be affected with the disease. When these plants are transferred to pots or beds in the greenhouse in the fall and are cut back severely, the most

extreme forms of malformation of the leaves and catacorolla frequently come into expression. The blossoms and leaves of healthy plants given the same treatment remain normal indefinitely.

SUBSEQUENT DISTRIBUTION OF THE VIRUS OF MOSAIC IN INOCULATED LEAVES AFTER CUTTING THE MIDRIBS OR LATERAL VEINS

In February, 1914, a series of tests was made to determine the effect of severing the midrib or the lateral veins upon the subsequent distribution of the virus in an inoculated leaf. In one series the midrib alone was carefully severed close to the base of the leaf blade (Pl. 63, leaf A).

In a second series the lateral veins were cut in the same manner along either side of the midrib (Pl. 63, leaf B).

In a third series a cut was made close to the midrib from a point near the apex nearly to the base on one side of the leaf, thus severing all the larger lateral veins on this side (Pl. 63, leaf C).

A sharp scalpel heated to redness was used for all cutting. This method not only insures complete sterilization of the instrument, but also serves to kill the tissues immediately in contact with the blade, thus searing over the freshly cut surfaces. After a brief wilting, turgidity is again established and growth and assimilation maintained, although more slowly, as would be expected (Table IV).

TABLE IV.—*Effect of severing the midrib or lateral veins, following inoculation, upon the distribution of the virus in the plant*

Number of plants treated.	Treatment.	Date treated.	Results.	Incubation period.
		1914.		*Days.*
13 Connecticut Broadleaf.	Inoculated at several points on either side of midrib near apex of leaf. Midrib then severed at base (Pl. 63, leaf A).	Feb. 7	9 mosaic, Feb. 27–28.	20–21
10 Connecticut Broadleaf.	.....do.....	...do.....	3 mosaic, Mar. 2–3...	26–27
Do.....	Inoculated at several points near middle of both halves of leaf near margins. Lateral veins then cut on both sides midrib from a point near apex nearly to base (Pl 63, leaf B).	...do.....	5 mosaic, Feb. 26–28.	19–21
Do.....	Inoculated at several points near middle of one-half of leaf near margin. This half cut away from midrib at a point near apex nearly to base (Pl. 63, leaf C).	...do.....	First symptom, Mar. 1–2.	24–25
15 Connecticut Broadleaf.	Inoculated at several points near apex of leaf only.	...do.....	6 mosaic, Feb. 25–27.	18–20
10 Connecticut Broadleaf	Control. Inoculated with healthy sap at several points near middle of one-half of leaf close to margin. Lateral veins cut as in leaf B, Plate 63.	...do.....	All healthy.....	
19 Connecticut Broadleaf.	Inoculated at several points near apex, and midrib severed at base.	Feb. 20	11 mosaic, Mar. 4–5..	[a] 15
Do.....	Inoculations made as in preceding test, but midrib not severed.	...do.....	10 mosaic, Mar. 4–5..	[a] 15

[a] About.

On February 25, 1914, five plants, three of which were White Burley and two Maryland Mammoth, were inoculated at the middle of one-half of a leaf near the margin and cut along the same side of the midrib as in leaf C, Plate 63. Five similar plants were inoculated in the same manner without cutting the leaf blade along the midrib. The disease made its appearance in these two lots of plants as follows:

Series inoculated and cut along the midrib:
Two White Burley plants became mosaic 11 days after inoculation.
One White Burley plant became mosaic 14 days after inoculation.
Two Maryland Mammoth plants became mosaic 18 days after inoculation.
Series inoculated but not cut along the midrib:
One plant remained healthy.
One White Burley plant became mosaic 10 days after inoculation.
Two Maryland Mammoth plants became mosaic 10 days after inoculation.
One Maryland Mammoth plant became mosaic 18 days after inoculation.

These tests are sufficient to show that cutting across the midrib or severing all the larger lateral veins on one or both sides of the midrib does not prevent the final dissemination of the virus from distant points of inoculation in the leaf to other leaves of the plant. Although it is possible that the virus dose not travel as rapidly following this treatment, the differences do not appear to be consistently and strikingly conspicuous. Even though cutting across the midrib near the petiole permanently interrupts the main vascular system of the leaf, yet multiplication and diffusion of the virus from cell to cell, aided perhaps by the finely anastomosing lateral veins would sooner or later allow the virus to reach the petiole and pass into the rest of the plant. To what extent the virus of mosaic is carried directly through the vascular system, along with the transpiration stream is not known.

REMOVAL OF THE VIRUS FROM THE HANDS BY THOROUGH WASHING

In the following experiments the hands were covered with fresh virus before handling the plants. Each leaf of a series of 10 plants was then rubbed vigorously between the fingers. Following this treatment the hands were washed thoroughly several times with soap and water and wiped dry. The leaves of young, healthy plants were then rubbed between the fingers as before. The results in Table V show that this is a practical and efficient means of removing infection from the hands.

TABLE V.—*Effect of washing the hands thoroughly with soap and water to remove the mosaic-disease virus. Inoculations made on January 31, 1916, with series of 10 young Connecticut Broadleaf tobacco plants*

Number of plants.	Treatment.	Results.
10	Leaves rubbed and pinched between the fingers after dipping the fingers in fresh virus.	10 mosaic.
10	Hands were washed with soap and water, but left wet. Leaves rubbed and pinched as before.	2 mosaic.
10	Hands again thoroughly washed with soap and water and carefully dried. Leaves handled as before.	All healthy.
10	Hands again covered with fresh virus and leaves handled as before.	10 mosaic.
10	Hands now thoroughly washed with soap and water and carefully wiped dry. Leaves handled as before.	All healthy.
10	Hands again dipped into fresh virus and leaves handled as before.	4 mosaic.
10	Hands not washed but merely wiped dry. Leaves handled as before.	1 mosaic.
10	Plants inoculated with tap water, using a needle.....	Do.

SOIL STERILIZATION IN THE SEED BED AND THE OCCURRENCE OF THE MOSAIC DISEASE

In the field the mosaic disease may make its appearance regardless of the type of soil or previous crop conditions. So far as soil infection is concerned, there seems to be no direct relation to previous outbreaks of the disease, either in the seed bed or in the field. As a matter of fact, thorough sterilization of the seed bed with steam does not necessarily control the occurrence of the disease in the field, as experiments carried out at Arlington, Va., in 1915, have shown. Mr. E. G. Beinhart, of the Office of Tobacco Investigations, contributes the following data relative to this sterilization:

A bed was newly made on a clay soil. Over the clay a mixture of sand, peat, and compost was laid to a depth of 8 inches, and the fertilizers were worked in before steaming was begun. Steam was furnished by a road roller which gave an average pressure of 100 pounds, the range being from 80 to 125 pounds.

In these experiments the following temperature relations were obtained:

TABLE VI.—*Temperatures secured at Arlington, Va., in 1915, in five different parts of a tobacco seed bed sterilized with steam. Readings taken immediately after lifting the pan, as well as one hour later*

Depth.	Reading taken.	Temperatures obtained.				
		1.	2.	3.	4.	5.
		°C.	°C.	°C.	°C.	°C.
Surface	Immediately after lifting pan.	100	100 – 101	99	99	100
Do	One hour later	96	96	.....	.....	.....
3 inches	Immediately after lifting pan.	99	.....	98	97	.....
Do	One hour later	99	.....	.....	.....	.....
4 inches	Immediately after lifting pan	.....	99	.....	.....	80
Do	One hour later	.....	98	.....	.....	.....
6 inches	Immediately after lifting pan.	80	84	92	90	70
Do	One hour later	86	94	.....	.....	.....
10 inches (subsoil.)	Immediately after lifting pan.	22	22	.....	.....	.....
Do	One hour later	30	.....	.....	.....	.....

At Mr. Beinhart's suggestion some green mosaic leaves, freshly picked, were buried in the soil at a depth of 4 inches during the process of sterilization. Likewise, fresh mosaic virus, mixed in certain proportions with soil, was also buried to a depth of 4 or 5 inches at the same time. Inoculation tests made at once showed that the leaves which were cooked to the point of disintegration, had completely lost their infectious properties, as well as the virus mixed with the soil. In control tests, the same virus mixed with soil in the same proportions, but not subjected to sterilization, remained highly infectious, as did unsterilized portions of green mosaic leaves from the same plants.

Although these experiments with buried mosaic material indicate the thoroughness of steam sterilization, practically every plant obtained from these beds and set in the field at Arlington, Va., sooner or later became mosaic diseased. Late in the season the mosaic disease also made its appearance in the beds themselves at some points. The occurrence of the disease in a thoroughly sterilized soil can not be reasonably explained on any other basis than that of infection reaching the plants from sources external to the soil.

RELATION OF THE MOSAIC DISEASE TO INFECTION IN THE SOIL

Although the mosaic disease is readily communicated to healthy plants by inoculation of the virus into the roots, the disease does not necessarily follow as a result of introducing large quantities of mosaic material into the soil so that the roots must ultimately reach it. Under such conditions the disease frequently does not occur at all, although in some experiments the buried, decomposing material still retained its infectious properties, as shown by inoculation tests. Infection from such material in the soil appears to depend upon injury to some portion of the root

system which allows the virus to gain an entrance at these points. Experiments have shown that the promptness and certainty of infection are greater when the green mosaic material is thoroughly mixed with the entire mass of soil just before transplanting than when it is buried carefully in the lower layers. The explanation seems to be that in the former case the injured roots of plants during transplanting are more likely to come directly in contact with infective material. In the latter case the injured roots are given an opportunity to heal before any portion of the extensive root system reaches the layers of mosaic material, and for this reason infection is greatly delayed, should it take place at all. Many healthy plants have been grown to maturity under these conditions, although an examination has shown that the roots have penetrated every portion of the layer of mosaic material. In fact, owing to the availability of additional plant food through the decomposition of the mosaic material, the plants have generally shown greater vigor and a darker green color than control plants which received no vegetable material.

In a long series of experiments the effect of replacing mosaic plants grown in 12-quart pails by young, healthy plants was studied. The results were rather uncertain and showed that healthy plants do not necessarily become mosaic, even though they immediately replace mosaic plants. In some instances several successive plants have developed the mosaic disease shortly after transplanting, followed by one or more plants which remained healthy. Here, also, immediate infection probably depends upon the fact that the injured roots of healthy transplanted seedlings in some instances happen to come directly in contact with some portion of the broken mosaic root system of the diseased plant just removed.

It is quite possible that injury due to underground parasites may be a factor in facilitating root infection in the mosaic disease of tobacco. During a series of pail experiments with plants grown in soil, to the lowermost layers of which chopped up mosaic leaves and stems had been added, the root systems of some of the plants became badly infested with nematodes. It is believed that their attacks were a factor in producing some of the infection which followed in these instances. Since it is known that the larval stages of tobacco flea-beetles feed upon the finer roots of tobacco and other solanaceous plants, it would be of considerable interest to know whether or not these parasites are able also to communicate the disease from the root systems of mosaic to healthy plants in the field.

BEHAVIOR OF NICOTIANA GLAUCA AFFECTED WITH THE MOSAIC DISEASE

It was at one time thought that *Nicotiana glauca* is immune to the mosaic disease of tobacco. It is now known that this species does acquire the disease by artificial inoculation, although perhaps less readily

than do varieties of *N. tabacum*. The symptoms are confined to a sparse and indistinct mottling along the veins of some of the leaves. This mottling in some instances is too faint to be detected readily, except in transmitted light, and may be entirely wanting. This behavior of *N. glauca* is rather exceptional and has been the subject of considerable investigation. In February, 1914, a number of young, vigorous plants of that species growing in the greenhouse were inoculated repeatedly with the virus of the mosaic disease until most of them showed more or less evidence of developing disease. Eight of these, which showed more clearly defined symptoms, were finally tested by injecting the expressed sap of each into a series of plants of *N. tabacum*. The sap of all proved exceptionally virulent, producing in most instances 100 per cent of infection in each lot of 10 plants. After the initial expression of the disease the symptoms gradually became more attenuated, until they were barely distinguishable. In July three of these plants were cut back severely and were immediately transplanted to the field. Growth was resumed, but no symptoms of the mosaic disease whatever could be detected. However, inoculation tests have shown that the sap of these plants contained the infective principle of the disease. In October these plants were again taken from the field and transplanted in the greenhouse for the winter. Although growth appeared normal and symptoms of the mosaic disease could not be detected with certainty, experiments have shown repeatedly that the infective principle of the disease was still present in the expressed sap. This behavior of *N. glauca* is not entirely without its analogy, since Baur,[1] working with infectious chlorosis of the Malvaceae, has found by grafting immune with susceptible sorts that the virus of the disease may pass into immune sorts of abutilon without producing any indications of disease. Baur is of the opinion, however, that the virus does not continue to live and to multiply in the infected immune plants after they have been severed from the diseased plants.

Experiments have shown that when scions of the immune species, *N. glutinosa*, have been grafted upon mosaic-diseased plants of *N. tabacum* the infective principle of the disease may pass into *N. glutinosa* without the subsequent development of symptoms of the mosaic disease.

It has not been determined whether the infective principle continues to live and to multiply in such *N. glutinosa* plants after they have been separated from the mosaic diseased plants of *N. tabacum*.

In the case of *N. glauca* it is evident that the infective principle, after being inoculated into the tissues of the leaves, propagates itself readily and becomes disseminated to all parts of the infected plant, producing systemic infection.

Although it has not yet been shown that a permanent systemic infection may occur in young growing plants of *N. tabacum* without the

[1] BAUR, Erwin. ÜBER DIE INFEKTIÖSE CHLOROSE DER MALVACEEN. *In* Sitzber. K. Preuss. Akad. Wiss., 1906, Heft 1, 11–29. 1906.

expression of symptoms, it is known that the infective principle does not necessarily produce evident symptoms wherever it is found. If half-grown plants become infected with the virus of the mosaic disease, the younger leaves show symptoms of disease, while the lowermost mature leaves remain healthy in appearance. Such leaves may contain the infective principle, however, if sufficient time has elapsed for general or systemic infection to take place.

Likewise, if nearly mature plants become infected, the corolla alone may show symptoms of disease. Subsequently all secondary branches become mosaic diseased, showing that the virus has migrated to all parts of the main stem, finally reaching and affecting new growing centers. If such dormant plants are severely cut back, even to the ground, all subsequent sucker growth becomes mosaic diseased.

In large, vigorous plants grown in the field systemic infection sometimes proceeds gradually from branch to branch. This has been shown with large plants producing many suckers. In some instances the uppermost suckers were badly diseased, while others lower down on the stalk appeared normal in all respects.

Although inoculation tests have shown that such suckers in some instances did not contain the active, infective principle at the time the sap was extracted, such suckers invariably become diseased sooner or later.

TRANSMISSION OF THE MOSAIC DISEASE OF TOBACCO BY PLANT LICE

It was first observed in the greenhouses at Arlington, Va., during the winter and spring of 1912 that plant lice were in some manner associated with outbreaks of the mosaic disease of tobacco. Experiments have since shown that the common and well-known green peach aphis, or spinach aphis (*Myzus persicae* Sulz.) may become an active carrier of the infective principle of the disease. These plant lice are very common in the greenhouse and may be found on a great variety of plants. In winter they multiply in great numbers upon tobacco plants and may even produce serious injury to these plants if allowed to multiply unchecked.

Many colonies of these plant lice obtained from different sources have been studied in their relation to the transmission of the mosaic disease. Colonies have been found which have failed to produce infection in healthy tobacco plants. Such colonies have been obtained from belladonna and cabbage plants, which are naturally immune to the disease. Colonies free from infection have also been obtained from healthy tobacco plants. On the other hand, experiments have shown that colonies obtained from mosaic-diseased tobacco plants may become very efficient disseminators of the infective principle of the disease.

In one of the earlier experiments carried out during the winter of 1912, a colony of *Myzus persicae* obtained from belladonna plants was

introduced upon young tobacco plants on January 18. These plant lice multiplied rapidly and remained upon the plants in great numbers throughout January, February, and March. On April 1 the plants were fumigated with the fumes of nicotine obtained by burning paper impregnated with nicotine to destroy the plant lice, which had stunted the plants severely. These plants were allowed to grow for several weeks longer and soon regained their normal green color. At the termination of the experiment none had developed the mosaic disease. A series of control plants of the same age, fumigated at intervals with nicotine fumes obtained as mentioned above to exclude plant lice, remained free from the mosaic disease throughout the period of the experiment.

Other colonies of *Myzus persicae* infesting mosaic-diseased tobacco plants produced the disease in great numbers of young tobacco seedlings kept in screened cages.

During the winter of 1915–16 additional experiments were carried out with colonies of *Myzus persicae* in the greenhouse at Arlington, Va. Colonies of these plant lice which proved to be free from infection were found, and many individuals were then transferred to the leaves of mosaic-diseased tobacco plants and allowed to multiply freely upon them. Individuals which had been reared upon these plants were then transferred with a fine camel's-hair brush to 13 young, healthy Connecticut Broadleaf tobacco plants. Twelve of these plants became mosaic-diseased within five to six weeks, one plant only remaining healthy. At the same time 15 control plants, which were kept free from plant lice at all times, remained free from the mosaic disease throughout the experiment.

In another series of experiments large numbers of *Myzus persicae* were again transferred from mosaic-diseased plants to two flats of very young tobacco seedlings. At the same time two similar flats were inclosed in screened cages and kept free from plant lice. Throughout the entire experiment the plants in these flats remained free from the mosaic disease. At the same time, however, great numbers of mosaic-diseased plants appeared in both flats which had been infested with plant lice transferred from the mosaic plants.

These experiments indicate that the green peach aphid may become an active carrier of the infective principle of the mosaic disease of tobacco; and they also show that these plant lice do not become active carriers of infection until they have been associated with mosaic-diseased plants.

Numerous experiments were also carried out in the greenhouse with a large, green species of plant louse, *Macrosiphum lactucae* Kalt., taken from lettuce plants. Colonies of these plant lice were confined upon mosaic-diseased tobacco plants and finally transferred from these plants at different intervals to very young, healthy tobacco plants. They soon established themselves upon the plants and multiplied so rapidly in

some instances as to produce heavy infestation, but in no instance did they produce infection in healthy plants. As a result of their infestations, however, temporary disturbances of a striking character were produced. Soon after these plant lice had begun to feed upon the young leaves, these became more or less curled and wrinkled, and rather large, conspicuous dark green spots came into evidence as a result of their punctures. This spotting, which only remotely resembled the mottling characteristic of the mosaic disease, was confined entirely to those leaves actually attacked, and disappeared soon after the removal of the plant lice from the plants. This disturbance more properly belongs to the class of disturbances described by Woods [1] as stigmonose, a term which he used to designate a more or less temporary and noninfectious pathological condition produced in carnations by plant lice and other insects.

Colonies of the common pelargonium plant louse (*Macrosiphum pelargonii* Kalt.) were also transferred to mosaic-diseased plants and subsequently to healthy tobacco plants. This plant louse did not take kindly to tobacco, and colonies could not be maintained upon these plants or any length of time—perhaps owing to the fact that they did not feed upon the plants. Transmission of the disease was not obtained with these plant lice; nor were temporary disturbances of any kind produced.

Under field conditions the large plant louse *Macrosiphum tabaci* Perg. appears to be an efficient carrier of the infective principle of the mosaic disease of tobacco. At the Arlington Experimental Farm during certain seasons this plant louse occurs in enormous numbers upon tobacco, tomatoes, datura, and other solanaceous plants. During the spring and summer of 1913 this species appeared suddenly, and swarmed upon these plants. Minor outbreaks have also occurred in subsequent years. There is strong reason for believing that the widespread epidemic of mosaic disease which affected tobacco, tomatoes, and datura during the season of 1913 at Arlington, Va., was associated with the presence of these plant lice. In late May and early June, soon after the young tobacco plants were transplanted to the field, colonies were found upon the undersides of the ground leaves of practically every tobacco plant in the field. These plant lice multiplied rapidly and remained upon the plants until early July. After this period they disappeared so completely from the plants that it was almost impossible to find a single individual in late July and August. In late September, however, heavy infestations were observed on tomato plants.

This plant louse rarely occurs in the greenhouses at Arlington. Recently seedling tobacco plants have been grown in screened cages out of doors and colonies of this plant louse taken from mosaic-diseased tobacco plants have been confined upon them for varying periods. Under these conditions successful transmission of the disease was obtained.

[1] WOODS, A. F. STIGMONOSE: A DISEASE OF CARNATIONS AND OTHER PINKS. U. S. Dept. Agr. Div. Veg. Physiol. and Path. Bul. 19, 30 p., 5 fig., 3 pl. 1900.

In several instances the plant louse *Macrosiphum tabaci* has become established in the seed beds at Arlington, and appears to have been associated with outbreaks of the mosaic disease which appeared in the infested areas.

Under greenhouse conditions experiments indicate that plant lice may become important disseminators of infection. Experience has also shown that the occurrence and spread of the disease in the greenhouse can not be controlled so long as the plant louse *Myzus persicae* is allowed to multiply unchecked.

If plant lice are excluded by fumigation, however, the occurrence and spread of the mosaic disease of tobacco becomes a negligible factor, provided contamination of the plants in the process of handling does not take place. Although white flies (*Aleyrodes vaporariorum* Westw.) are also troublesome pests upon tobacco in the greenhouse, they do not appear to be actively concerned with the spread of the disease. Preliminary experiments with these insects, obtained from mosaic-diseased plants and confined upon healthy plants in screened cages, have also given negative results. Red spiders (*Tetranychus telarius* L.), which do not take kindly to tobacco, have given the same results.

Although in the United States plant lice do not appear to be especially troublesome pests on tobacco in the field, it appears that they sometimes cause serious injury to tobacco in Europe and elsewhere. Preissecker[1] states that during some seasons they fairly cover the leaves of tobacco plants and produce far more injury than is usually estimated. It is especially interesting to note that Preissecker[1] has also observed that the mosaic disease of tobacco is associated with attacks of plant lice..

Die von Blattläusen verwundeten Blätter sind begreiflicherweise später gewöhnlich auch von anderen Krankheiten (Pilzen, Mosaik- und Pockenkrankheit) viel mehr heimgesucht als die unbeschädigten, und es ist deshalb von allem Anfange auf die Entfernung und Fernhaltung der Blattläuse ein besonderes Augenmerk zu richten.

Preissecker again discusses the widespread occurrence of plant lice upon tobacco in the Imoskaner region in a later article,[2] and mentions that the species *Myzus plantaginis* Pass. is very common on tobacco in Dalmatia. Other species are also mentioned. He states that plant lice are especially injurious to young plants in the seed bed. Concerning the abundance of plant lice upon tobacco in the field, he[2] says:

Im Jahre 1903 gab es von Anfang Juni bis zur Ernte Blattläuse auf Tabak im ganzen Imoskaner Bezirke; man traf Pflanzungen in denen jeder Stock on allen Mutter- und- Spitzblättern, u. zw. meist auf beiden Seiten derselben, von den Läusen so dicht besetzt war, dass sie hier und da übereinander kriechen mussten, um Platz zu finden. . . .

[1] PREISSECKER, Karl. EIN KLEINER BEITRAG ZUR KENNTNIS DES TABAKBAUES IM IMOSKANER TABAKBAUGEBIETE. *In* Fach. Mitt. Österr. Tabakregie, Jahrg. 3, Heft 2, p. 1–31, 19 fig. 1903.

[2] PREISSECKER, Karl. EIN KLEINER BEITRAG ZUR KENNTNIS DES TABAKBAUES IM IMOSKANER TABAKBAUGEBIETE. *In* Fach. Mitt. Österr. Tabakregie, Jahrg. 5, Heft 1, p. 1–44, fig. 41–75 (1 pl.). 1905.

Although Preissecker casually observed that there was some relation between the presence of plant lice upon tobacco plants and the subsequent occurrence of the mosaic disease, it does not appear that he looked upon them as actual carriers of the infective principle of the disease.

SUMMARY

(1) The virus of the mosaic disease of tobacco is present in the trichomes of the leaves, as well as in the tissues of the lamina. The disease may be communicated to healthy plants by inoculating the virus into the trichomes alone.

(2) The infective principle of the disease does not readily invade uninjured trichomes or leaf tissues when merely sprayed upon the plants. Infection readily follows when the virus is sprayed upon the leaves and subsequently rubbed in.

(3) Infection is more likely to follow if the virus is inoculated into the leaves at more than one point.

(4) Cutting across the midrib at the base of the leaf, or severing all the larger veins on one or both sides of the midrib, does not prevent the final dissemination of the virus from distant points of inoculation in the leaf to other leaves on the plant.

(5) Thorough washing with soap and water serves to remove the virus from the hands for all practical purposes.

(6) Thorough steam sterilization of the soil of the seed bed completely destroys any virus of the mosaic disease of tobacco which may be present in the soil.

(7) The mosaic disease of tobacco does not necessarily follow when large quantities of mosaic-diseased material are introduced into the soil so that the roots of healthy tobacco plants must ultimately reach it. Infection from such material appears to depend upon injury to some portion of the root system which allows the virus to enter at these points. It is possible that root parasites may sometimes produce this injury to the roots and root hairs.

(8) The species *Nicotiana glauca* is susceptible to the mosaic disease of tobacco, although visible symptoms of the disease may be very slight. The sap of such plants, although apparently but little affected by the disease, so far as visible symptoms are concerned, is highly infectious to healthy plants of *N. tabacum*.

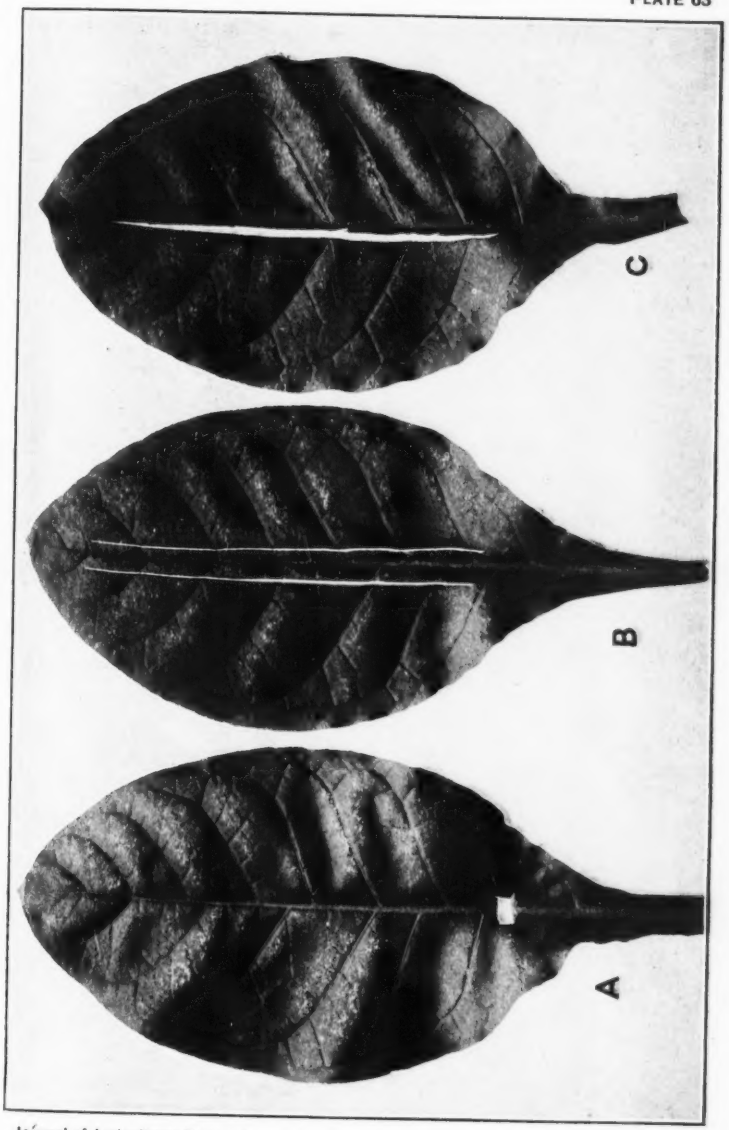
(9) Some species of aphids may become active carriers of the infective principle of the mosaic disease. Experiments have shown that the green peach aphis (*Myzus persicae*) may become an active carrier of infection in the greenhouse, after it has been feeding upon mosaic-diseased plants. Not all species of aphids appear to transfer the disease with the same readiness. Negative results were always obtained with the large lettuce aphis, *Macrosiphum lactucae*. Under field conditions the large plant louse *Macrosiphum tabaci* which sometimes becomes very common on

solanaceous plants, appears to be an efficient carrier of the infective principle of the disease.

(10) Red spiders, which rarely attack tobacco in the greenhouse have consistently given negative results so far as the transmission of the disease is concerned. White flies, which are often very troublesome pests upon tobacco in the greenhouse, do not appear to be actively concerned with the transmission of the disease.

PLATE 63

Leaves of tobacco showing method of severing the midrib and lateral veins in studying the distribution of the virus from the point of inoculation. Leaf A, midrib severed at base. Leaf B, lateral veins on both sides of midrib severed. Leaf C, lateral veins on one side of midrib severed.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A STUDY OF THE PROTEINS OF CERTAIN INSECTS WITH REFERENCE TO THEIR VALUE AS FOOD FOR POULTRY

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In view of the present high cost of living, it is well to discuss and to consider seriously the utilization of every available source of sound animal protein, even though such proteins may have hitherto been looked upon as of not enough economical importance to warrant their utilization.

The object of this paper is to call attention to the efficiency of animal proteins as compared to vegetable proteins, and also to show by comparative analyses that two very common insects contain proteins which are very similar in character to those contained in the proteins of the higher animals which furnish a large part of our food supply.

Within recent years wonderful progress has been made in our knowledge of the character and properties of proteins. Formerly it was assumed that all proteins were of equal value in maintaining nitrogen equilibrium, regardless of whether such proteins were of animal or vegetable origin.

Thomas (2),[2] who was a pupil of Rubner, was the first to demonstrate experimentally the fact that animal proteins are much superior to vegetable proteins in maintaining nitrogen equilibrium in the animal body.

In order to demonstrate this fact, he performed the following classical experiment on his own body. In his diet he took large quantities of starch and sugar, and determined the minimum loss of protein under these conditions. He then took meat protein in an amount equivalent to this minimum quantity destroyed and found that if the food was divided into six portions, taken four hours apart, there was no loss of body protein. His experiments were carried still farther, and he showed the relative biological values of proteins of different origin. The following list shows the minimum amounts of different proteins required to protect body protein from loss:

	Gm.		Gm.
Meat protein	30	Bean protein	54
Milk protein	31	Bread protein	76
Rice protein	34	Indian corn protein	102
Potato protein	38		

[1] The writer begs to acknowledge his indebtedness to the late Dr. J. H. Kastle, who was much interested in nutrition problems and had suggested a study of the proteins of the grasshopper.

[2] Reference is made by number to "Literature cited," p. 637.

He also states that there can be no doubt whatever as regards the superior value of the proteins of meat, fish, eggs, and milk over those of bread, beans, and Indian corn. The proteins of rice and potatoes hold an intermediate position.

The difference in the efficiency of animal versus vegetable proteins is further demonstrated by most wild animals in their natural selection of food. It is well known that all wild animals of the cat species live altogether on animal proteins. A recent investigation by the United States Biological Survey (1) in regard to the character of the food consumed by the wild birds of this country reveals the very interesting fact that an average analysis of the contents of the craws of 14 species of wild birds shows that approximately 50 per cent of all the food consumed in a year's time consisted of animal matter in the form of insects. If the fact that insects are only available for about six months of the year is taken into consideration, it is to be assumed that the diet of the wild birds consists almost entirely of animal protein during the season in which insects are available. It is also to be noted in this connection that the parent birds feed their young on a purely animal diet, thus exhibiting a wonderful instinct in the selection of a food that is most efficient for the rapid growth of their young. The avidity with which domestic fowls, when allowed to range, seek insect food is familiar to all, and it is a well-known fact that poultry thrive best when they have access to this kind of food.

After noting these phenomena in the selection of food by both wild and domesticated birds, it is only natural to inquire whether there is any chemical evidence as to the nature of the proteins contained in the various insects which will substantiate the birds' instinctive selection of this particular kind of food.

Through the recent researches of Osborne and Mendel (3–5) of Yale University and the Connecticut Experiment Station, it has been conclusively shown that the growth-promoting properties of certain proteins are due to the presence of that kind of protein which is capable of yielding upon hydrolysis the amino acids lysin, cystin, and tryptophane. Then, if the instinct of the bird in its selection of its food is a true guide, we would expect a protein analysis to show a considerable amount of these growth-promoting amino-acid groups present in this type of food.

In fact, protein determinations made by the writer on two common insects, the June bug (*Lachnosterna* sp.) and the grasshopper (*Melanoplus* spp.), showed such a large percentage of protein present in the dry state that a further study of the character of the proteins present, as revealed by the Van Slyke method for protein hydrolysis, was carried out. The results obtained are shown in Table I, under the proper headings, together with the results obtained by the same method of analysis on a very tender piece of cooked beef roast and the cooked tender white breast meat of a turkey. The specimens of beef roast and turkey were

selected for comparison because they represent the more common higher types of animal proteins.

TABLE I.—*Percentage of amino-acid groups in animal proteins from different sources*

Group.	Grass-hoppers.	June bugs.	Beef roast.	Turkey white meat.
Ammonia nitrogen	9. 14	8. 96	3. 27	5. 65
Melanin nitrogen	3. 42	6. 78	5. 22	1. 72
Arginin nitrogen	14. 98	11. 53	15. 44	14. 72
Histidin nitrogen	5. 62	6. 57	13. 34	18. 23
Cystin nitrogen	. 23	. 35	. 49	. 47
Lysin nitrogen	8. 04	8. 02	8. 40	7. 67
Amino nitrogen (in filtrate from bases)	52. 87	50. 80	40. 89	42. 41
Non-amino nitrogen (in filtrate from bases)	4. 32	5. 84	9. 38	7. 26
Total	98. 62	98. 85	96. 43	98. 13

As a whole, the results show considerable similarity for proteins varying so widely in their sources of origin. The chief points to be taken into consideration in an analysis of this kind, as showing important points in similarity or differences, are the four amino-acid groups, arginin, histidin, cystin, and lysin. In the arginin determinations very closely agreeing results have been obtained on each of the different proteins analyzed. In the histidin determinations there is considerable variation. The result for this group in the first and second analyses is one-half of that in the third and one-third of that obtained in the fourth analysis. Figures for the cystin group show an increase of one-half in the second analysis over the first, and more than twice as much in the third and fourth analyses as in the first. The determinations in the lysin group show a remarkably close agreement in all the analyses. In the light of our present knowledge this is by far one of the most important groups contained in proteins, from the standpoint of growth and nutrition.

For the purpose of showing further points of interest in connection with the grasshopper the following work was carried out:

On September 23, 1916, about 200 gm. of grasshoppers were caught, killed by means of potassium cyanid, dried at 100° C. until free from water, ground in a mortar, and placed in a ground-glass-stoppered bottle. With the exception of the opening of the bottle for weighing out portions for protein, fat, and mineral-constituent determinations, the material has remained in the laboratory unmolested until the present time. A protein determination made recently on the same material after standing in the laboratory in this condition for seven months shows that there has been no alteration in the protein content during this period of time, which demonstrates that the dry material can be kept indefinitely.

The following determinations were made on the moisture-free material:

	Per cent.
Protein	75.28
Fat (ether extract)	7.21
Ash (crude)	5.61
Mineral constituents:	
Silica	.600
Iron oxid (Fe_2O_3)	.107
Manganese oxid (Mn_3O_4)	.008
Calcium oxid	.360
Magnesium oxid	.394
Potassium oxid	1.202
Sodium oxid	.335
Phosphorus pentoxid	1.190
Sulphur	.380
Carbon dioxid and unconsumed carbon, by difference	1.034
Total mineral constituents	5.610

From the results obtained in the analysis of the water-free substance it is to be observed that the dried remains of grasshoppers contain a high percentage of valuable protein and also notable amounts of fat, phosphorus, and potassium.

At different periods in the world's history this insect has occurred in such great numbers as to make it necessary to provide means for its immediate destruction. Whiting (8) describes a plague of locusts or grasshoppers which occurred in Palestine in the summer of 1915. He characterizes this plague as being one of the greatest of all grasshopper plagues on record, both in regard to numbers and to the amount of destruction done. The following paragraph is taken from his article (8, p. 513):

> Quantities were now gathered by the poorer Bethlehemites. A few ate them roasted, describing the taste as delicious, especially the females full of eggs. Still the main reason for collecting them was in order to secure the small bonus offered by the local government of Bethlehem. Thus tons were destroyed, being buried alive till several ancient abandoned cisterns were filled, while in surrounding villages each family was required to produce a stipulated weight. Likewise in Jaffa they were destroyed by being thrown into the Mediterranean, and when washed ashore dead and dried on the beach, were collected and used as fuel in the public "Turkish baths" and ovens.

While there has never been such a plague in this country as the one just described, grasshoppers have been known to occur in such numbers as to make it necessary to provide means for their control (6). Walton (7) in a bulletin of the United States Department of Agriculture, cites instances where as many as 3 bushels of grasshoppers have been harvested per acre by means of a mechanical device known as the grasshopperdozer. It is quite probable that in many instances with suitable machinery for catching, drying, and grinding these insects they might afford a new source of a high-grade protein in all respects the equivalent of meat meal, which could be made to serve an economical use in the affairs of man, such as preparing balanced rations for swine, poultry, and other live stock.

June bugs, while containing a slightly greater amount of protein than the grasshopper, and of equal value, could not be made an economical source of protein because of their limited number and the short time in which they are available.

From the data herein contained we may draw the following conclusions:

(1) That the instinct in wild and domesticated birds which guides them in their natural selection of the most efficient food is confirmed by the high lysin content found in the insects thus far examined.

(2) That grasshoppers deprived of their moisture contain a higher protein content than commercial meat meal, and in all probability could be made an efficient substitute therefor.

LITERATURE CITED

(1) BEAL, F. E. L.
1915. SOME COMMON BIRDS USEFUL TO THE FARMER. U. S. Dept. Agr. Farmer's Bul. 630, 27 p., 23 fig.

(2) LUSK, Graham.
1906. THE ELEMENTS OF THE SCIENCE OF NUTRITION. 326 p., 11 fig. Philadelphia and London.

(3) OSBORNE, T. B., and MENDEL, L. B.
1914. AMINO-ACIDS IN NUTRITION AND GROWTH. *In* Jour. Biol. Chem., v. 17, no. 3, p. 325-349.

(4) ——— ———.
1915. THE COMPARATIVE NUTRITIVE VALUE OF CERTAIN PROTEINS IN GROWTH AND THE PROBLEM OF THE PROTEIN MINIMUM. *In* Jour. Biol. Chem., v. 20, no. 3, p. 351-390.

(5) ——— ———.
1916. THE AMINO-ACID MINIMUM FOR MAINTENANCE AND GROWTH, AS EXEMPLIFIED BY FURTHER EXPERIMENTS WITH LYSINE AND TRYPTOPHANE. *In* Jour. Biol. Chem., v. 25, no. 1, p. 1-12.

(6) U. S. ENTOMOLOGICAL COMMISSION.
1880. SECOND REPORT ... FOR THE YEARS 1878 AND 1879, RELATING TO THE ROCKY MOUNTAIN LOCUST AND THE WESTERN CRICKET ... 322+80 p., 17 pl., 7 maps. Washington, D. C.

(7) WALTON, W. R.
1916. GRASSHOPPER CONTROL IN RELATION TO CEREAL AND FORAGE CROPS. U. S. Dept. Agr. Farmer's Bul. 747, 18 p., 21 fig.

(8) WHITING, J. D.
1915. JERUSALEM'S LOCUST PLAGUE. *In* Nat. Geog. Mag., v. 28, no. 6, p. 511-550, illus.

WIND-BLOWN RAIN, A FACTOR IN DISEASE DISSEMINATION

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INTRODUCTION

In an earlier article [1] the author presented data from field experiments which lead to the conclusion that the spread of that disease was due to the combined action of wind and rain. It was also shown that the spread of similar diseases of plants affecting the leaves, flowers, fruits, and twigs, caused by motile bacteria had not been satisfactorily explained by investigators, while nothing in the literature on the subject precluded the possibility of such an explanation applying equally as well in these cases. Numerous statements appear which permit a very general application of this explanation.

The film of water over the surface of the affected leaves caused by dew contains viable bacteria which emanate from the lesions, as was demonstrated by several experiments, and it was held to be reasonable that this condition would exist during rains. The spread of such a suspension of bacteria by the combined action of wind and rain most plausibly explained the dissemination of the disease noted in the field.

Experiments have been conducted with the object of analyzing this agency of disease dissemination, and, so far as the results of laboratory tests permit application to natural and field conditions, added support to the earlier conclusions has been the result. The method and the results of these experiments in which the influence of size of drops, distance of fall, depth of surface film, elevation and inclination of surface film, and motion of the air upon the distance of splash have been studied are presented here, together with a consideration of the importance of this agency of disease dissemination, which is justified by the newer information.

METHOD AND APPARATUS

Several drawn-glass droppers of different diameter were made and fitted separately to a burette having a glass stopcock. The diameters were such as permitted drops of 0.02, 0.04, 0.06, and 0.1 c. c. in volume to fall. Such surfaces as dry glass plates, dry blotting papers, wet glass plates, saturated blotting papers, and water 1 cm. deep in a petri dish were used and in this way the results of the fall upon a dry impervious surface, a dry porous surface, a very thin film of water (such as would

[1] FAULWETTER, R. C. DISSEMINATION OF THE ANGULAR LEAFSPOT OF COTTON. *In* Jour. Agr. Research, v. 8, no. 12, 457–475, 2 fig. 1917. Literature cited, p. 473–475.

remain over a saturated piece of blotting paper), a medium layer of water (such as would remain upon a clean, level glass plate) and a very thick layer of water (as that in a petri dish) were observed.

In the earlier work a large pane of glass ruled with a series of concentric arcs varying successively, 2 inches in radius, similar though on a much larger scale to the Jeffers counting plate used in bacteriological laboratories, was used to determine the number and position of the splash drops. Later two such panes of glass placed end to end were used and these afforded a total distance of 114 inches, which served all needs until the wind factor was introduced. At the latter stage of the work acetic acid was applied to the point of impact by a finely drawn siphon and with neutral or slightly alkaline litmus blotters 6 inches square placed in the path of the wind the limits of splash were easily determined.

The level surface used at the plane of the counter was supported upon two strips of glass placed across a small tray. When inclined surfaces were used, or the level surface elevated above the counter, a glass plate was placed in a clamp and fastened to a ring stand. The level plates were adjusted with a spirit level and the inclined ones were placed at definite angles to the level plate, as is noted below. The blotting paper surfaces were always placed upon a glass plate whether used dry or wet, level or inclined.

NATURE OF A SPLASH

A single drop falling 12 inches onto a clean dry glass plate does not cause a splash. This was repeated 100 times with each size of drop with the same result. The same is true of a drop falling 24 inches, while at 48 inches the largest drop (0.1 c. c.) did break in a few instances and scatter splash drops over the counter. When, however, two drops fall consecutively upon the same spot, even the smallest (0.02 c. c.) will cause a splash when falling but 12 inches.

This experiment, repeated with pieces of dry blotting paper, gave the same result in the case of single drops, though with the largest drop falling 12 inches an increasing number of splash drops appeared after 2, 5, and 10 drops were allowed to fall upon the same place, showing that the nearer saturated the blotting paper became, the more water became available in the surface film, and this was broken up and scattered by the impact of the falling drops.

A dilute eosin solution was applied to the surface of the glass plate and the saturated blotting paper in many of the experiments, and in all such cases the stain appeared upon the counter. When acetic acid was supplied to the plate at the point of impact as mentioned above, one never failed to note the change of color of the litmus paper where splash drops fell upon it.

These facts justify the conclusion that the splash drops scattered from the point of impact of a falling drop are made primarily of the water

composing the surface film at the point of impact. Perhaps in some cases water of the fallen drop is scattered, but the greater part of it remains as a part of the surface film and is splashed by succeeding drops.

NUMBER AND DISTRIBUTION OF SPLASH DROPS

While it was a relatively simple process to find the distances of those splash drops scattered farthest over a quadrant of a circle on the counter which was used, it was difficult to obtain an accurate count of the total number of splash drops in this way. In every instance many of the smaller drops, varying from a sixteenth of an inch in diameter to zero, evaporated before the count could be completed. Finally, to determine this point, the acetic-acid and litmus-paper method was resorted to. Five 0.02-c. c. drops falling 16 feet upon a glass plate covered with a solution of acetic acid scattered 495 drops over an eighth of a circle between 2 and 24 inches from the point of impact. When calculated, these figures show that each drop of that size falling that distance broke off and scattered 795 drops over a circle with a 24-inch radius.

The distribution of these splash drops is given in Table I, and it will be noticed that the modal class or distance is between 4 and 6 inches; yet the mean distance when determined is 7.1 inches.

TABLE I.—*Number of splash drops in concentric circles of varying radii, with the determination of the mean distance of all the drops*

Drops between circles of given radii.		Calculation of the mean distance.	
Radii.	Number of drops.	Distance of the class.	Product.
Inches.		*Inches.*	
0 to 2	32	1	32
2 to 4	824	3	2,472
4 to 6	1,008	5	5,040
6 to 8	800	7	5,600
8 to 10	472	9	4,248
10 to 12	384	11	4,224
12 to 14	288	13	3,744
14 to 16	96	15	1,440
16 to 18	16	17	272
18 to 20	32	19	608
20 to 22	8	21	168
22 to 24	16	23	368
	3,976	.....	28,216÷3,976=7.1 inches, mean.

A reproduction of the distribution of these drops is given in figure 1, showing the relative distances and orientation more satisfactorily than that of the foregoing table. A fact prominent in this phase of the work is the presence of the larger splash drops at the extreme distances. The smaller ones are more abundant near the point of impact. With-

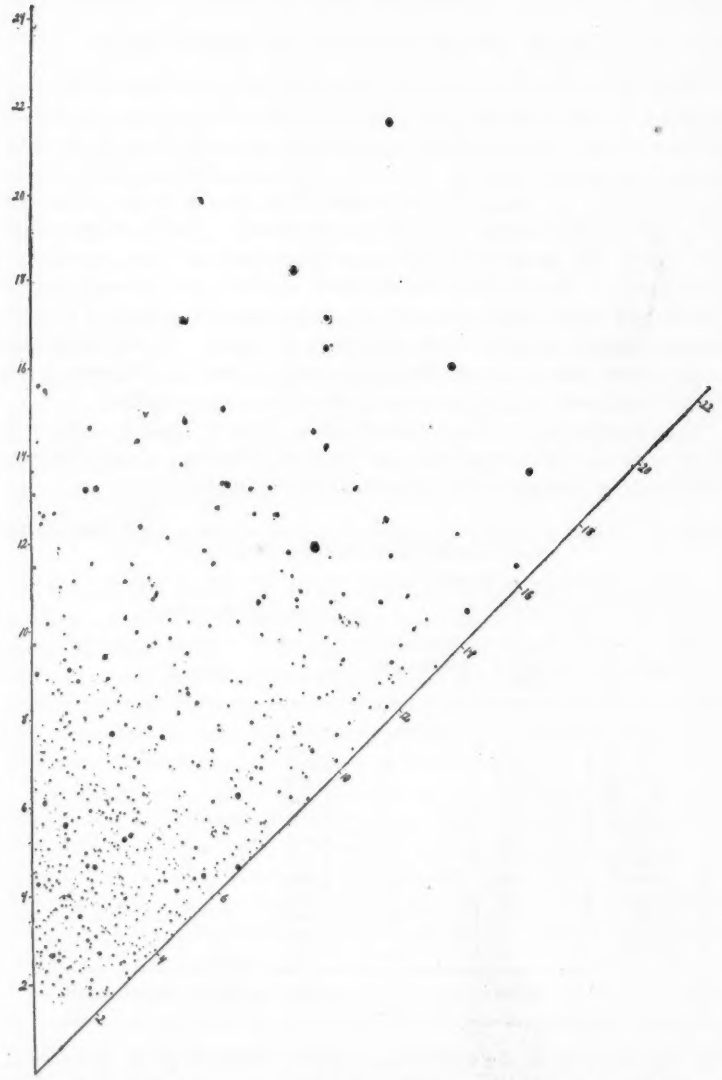

FIG. 1.—Graph showing the number and distribution of splash drops from five 0.02-c. c. drops falling 16 feet upon wet glass plate over an eighth of a circle.

out doubt all are cleaved from the surface film at the same time, and all leave the point of impact with the same energy. The only explanation for the presence of the larger drops at the greater distances must lie in the difference in resistance offered by the atmosphere, since the smaller drops would experience greater relative resistance than the larger ones.

SPLASH FROM A HORIZONTAL SURFACE AT THE LEVEL OF THE COUNTER

The greatest distance of splash results from the fall of the largest drop onto the thin film of water afforded by the wet blotting paper when falling 12 inches. Other things being equal, the distance of splash varies as the size of the drop varies, though not in direct proportion. With drops of each size, respectively, the distance of splash is greater from the wet glass plate than from the water in the petri dish.

The same relation exists in all the tests made with the drops falling 24 and 48 inches, with the exception in the latter case, where the distances from blotting paper and the glass plate were equal in two instances. With the tests made at greater heights, 8 and 16 feet, the thick layer of water in the petri dish was eliminated, since such a factor has no place in the application of the work to field conditions and since the relation of a deep layer of water to the other layers used had been satisfactorily established.

The figures given in Table II represent the extremes of splash in inches under each of the various sets of conditions and in general show the relation between size of drops, distance of fall, and thickness of surface film in the determination of this distance. The mean distance of all the splash drops farther than 6 inches resulting from the 1-, 2-, and 4-foot falls and the average of the extremes of each of 50 single drops falling 8 and 16 feet present the same relation of factors.

TABLE II.—*Distance (in inches) of splashes, giving the maximum, mean, and average of the maximums in 50 trials*

Size of drop.	Surface of impact.	Maximum.					Mean.			Average of maximums.	
	Distance of fall .... feet	1	2	4	8	16	1	2	4	8	16
C. c.											
0.1	Blotting paper	26	34	40	54	56	13.5	18.1	20.8	40	45
	Glass plate	20	36	40	42	48	12.0	15.5	17.8	33	35
	Petri dish	18	22	28	.....	.....	9.3	13.1	14.1	.....	.....
.06	Blotting paper	24	30	38	42	46	12.2	15.3	18.4	39	36
	Glass plate	20	14	36	32	40	10.9	12.8	17 0	28	29
	Petri dish	14	18	22	.....	.....	8.4	11.4	13.4	.....	.....
.04	Blotting paper	18	22	32	36	40	10.8	13.2	15.9	29	33
	Glass plate	12	16	32	24	38	8.7	9.5	14.8	19	26
	Petri dish	12	16	20	.....	.....	8.1	9.3	11.1	.....	.....
.02	Blotting paper	16	26	32	30	34	8.6	12.8	14.9	26	26
	Glass plate	10	16	26	24	24	7.3	9.9	11.6	15	18
	Petri dish	0	14	16	.....	.....	0.0	8.8	9.5	.....	.....

SPLASH FROM AN ELEVATED HORIZONTAL SURFACE

The total impetus of the splash drop is not expended in the experiments described above as is shown by the results obtained when the surface of impact is elevated above the counter. These observations were made with drops falling 16 feet upon a glass plate and a wet blotting paper surface elevated 24 inches above the counter, and the results are tabulated in Table III. In the case of the 0.02-c. c. drop falling onto the glass plate data are given for elevations of 3, 4, and 7 feet.

TABLE III.—*Distance (in inches) of splashes from horizontal surfaces, drops falling 16 feet*

Size of drop.	Surface of impact.	Maximum distance after many (100+) drops had fallen.				
Elevation of surface above counter ..... inches ..		0	24	36	48	84
C. c.						
0.1	Blotting paper	56	64	.....	.....	.....
	Glass plate	48	72	.....	.....	.....
.06	Blotting paper	46	56	.....	.....	.....
	Glass plate	40	64	.....	.....	.....
.04	Blotting paper	40	54	.....	.....	.....
	Glass plate	38	56	.....	.....	.....
.02	Blotting paper	34	36	.....	.....	.....
	Glass plate	34	40	42	38	42

SPLASH FROM AN INCLINED SURFACE

The orientation of the splash drops from a glass plate inclined 45° at the level of the counter differed from those from the level plate. With the semicircles of the counter divided into one central quadrant and two bordering octants and the centers coinciding with the point of impact, the splash drops arranged themselves in greatest numbers over the octants at the sides. Fewer drops fell just within the limits of the quadrant, while more fell along the median line. The latter never attained the distance of those at the sides. When leaving the point of impact, they ascend very little, if at all, but travel outward and downward. Those going to the sides ascend at first and then fall, similarly to the splash drops from a level surface.

As in this case, too, the total impetus is not expended when the surface is at the level of the counter. With the elevation of the inclined surface the net result of the glancing blow of the falling drop is observed. Those splash drops traveling along the median line of the counter—that is, at right angles to the inclined surface—increase in extreme distance until the optimum elevation is reached, where they exceed the distance of those going to the sides. The results of the 0.02-c. c. drop falling 16 feet upon the glass plate level and inclined 30° and 45° at various elevations above the counter are given in Table IV. It is to be noted that the maximum distance of splash is least from the level plate and greatest from that inclined 30°.

TABLE IV.—*Maximum distance (in inches) of the splash of a 0.02-c. c. drop falling 16 feet upon level and inclined wet glass plates*

Elevation of surface of impact above counter.	Level plate.	Plate inclined 45°.	Plate inclined 30°.
Feet.			
0	24	28	46
1	.....	.....	50
2	40	52	56
3	42	52	60
4	38	52	66
5	.....	.....	64
7	42	.....	66

EFFECT OF WIND UPON DISTANCE OF SPLASH

As mentioned above, the methods of the experiments were altered when wind was introduced into the work. An 18-inch electric fan was standardized with a wind gauge. While running at its greatest speed, the air was moving at the approximate rate of 10 miles per hour, 5 feet from the fan. In the experiments conducted, the fan was placed 5 feet from the surface of the splash, which itself was elevated 3 feet above the floor. Drops were permitted to fall 16 feet onto a clean glass plate which was very slightly inclined, in order that the surface film might be relatively thin. Dilute acetic acid was supplied to the plate near the point of impact by a siphon from a reservoir. In this way the falling drop scattered a solution of acetic acid and the wind blew these splash drops at the approximate rate of 10 miles per hour. The velocity of the wind was being constantly retarded by friction with the surrounding quiet air, and in this respect the extreme distance of splash was less than it would have been had the whole air mass been moving at the same rate. Litmus blotters were placed upon the floor at distances of 6, 8, 10, 12, 14, 16, and 18 feet from the point of impact in the path of the wind. After an hour's running the blotters at 6 and 8 feet were almost entirely red, those at 10, 12, and 14 feet were well spotted with red, while that at 16 feet showed several, and at 18 feet two red spots. Thus, it is evident that water was blown as far as 18 feet under the conditions of this experiment.

It was noted above that the larger splash drops exceeded the distance of the smaller splash drops. This does not obtain when the splash takes place in the wind, since the direction of atmospheric resistance is altered, and the smaller drops are borne farther than the larger, heavier ones. Considering the fact that splash drops vary in size from ⅛ inch in diameter to zero, the smallest ones may be carried correspondingly greater distances than the larger. These, without doubt, evaporated in transit in our experiments because of the dry atmosphere in the laboratory. In a humid atmosphere it is possible these may be carried

farther. Continual collisions between splash drops and rain drops occur in the field, and because of this many of the former may never reach their extreme distance at the prevailing wind velocity, though, without doubt, some of them will exceed the distance determined in the laboratory.

COMPARISON OF THESE METHODS WITH NATURAL CONDITIONS

It may be true that there are points in the discussion of these experiments where the justification for comparison is less than in others, yet on the whole, the results indicate the probabilities which exist, and these probabilities confirm the conclusions reached in the field where the spread of the angular leafspot of cotton was observed. An analysis of all the factors in their resemblance to natural conditions is made, in order to remove whatever doubt may exist on this point.

The drops of the sizes used afford a means of comparison of the effect of size and volume of drop on the number of splash drops and the distance of splash. It is recognized that the larger drops used are much larger than raindrops, yet the smallest one comes well within the limits of those in a winter rain where comparisons were made. It was found that drops of the same volume falling equal distances upon dry blotting paper cause wet spots of relatively equal sizes—that is, 25 of the 0.02-c. c. drops falling 16 feet made spots on the blotting paper with a minimum diameter of 14 mm., a maximum of 18 mm., and an average of 16.03 mm. The 0.04-c. c. drop made a spot with a minimum diameter of 19 mm., a maximum of 25 mm., and an average of 21.08 mm. Of 106 drops measured during a rain on the morning of February 20, 1917, fourteen drops were within the limits of the 0.02-c. c. drop as measured and compared in the way outlined above. Those of a summer rain have a greater average volume so that they more closely equal the size of the 0.02-c. c. drop used. It is only this drop which is compared to raindrops, though the others used show the variation in the results due to the variation of this factor.

None of the surfaces used can be closely compared with those of cotton leaves, though that condition is approximated most closely by the inclined glass plate. In that case the glass surface holds a film of water thicker than the blotting paper does and thinner than that of a level plate. There are places about the margins and veins of leaves where water gathers to greater depths than over the other parts, so that a variation of depth of film exists which is approximated by some one or another film used.

The stability of the surface of impact in the experiments is a factor which does not exist in the field. Leaves during a storm are constantly in motion and the petiole affords a springlike support which permits the leaf to yield after the impact of a drop. There are numerous instances also in which the leaves meet the falling drop while moving

toward it in the wind and increase the force of impact, in that way increasing the number of splash drops and distance of splash.

The greatest distance of fall (16 feet) was the highest available in the laboratory. The smallest drop used had probably reached its maximum velocity when falling this distance. If the distance of splash as a measure of the force of impact is an indication of the velocity of the falling drop, this is true, as is shown in Table II, where the distance of splash at 4, 8, and 16 feet from blotting paper and glass plates are relatively the same. This conclusion supports our measurement of raindrops as compared to the 0.02-c. c. drop, since the atmospheric resistance retards an acceleration of velocity beyond a definite maximum, and both our 0.02-c. c. drop and the raindrops had reached this maximum when they were measured.

The influence of the wind was not further investigated because of the limited apparatus available. The fan used produced a velocity of 10 miles per hour at a distance of 5 feet. It was thought best to keep that far from the fan because of the small size of the air cone in motion nearer it. At the distance used, all the air surrounding the surface of impact was moving uniformly and the conditions were most favorable. When it is noted that the distance of splash was increased by such a wind velocity to 18 feet and that this velocity is almost a constant feature of the summer thunderstorms of this region, it is readily seen that this distance of splash is not to be unexpected in the field. In the graphs in the article already cited [1] it is shown that—

the wind reaches a velocity of 25, 29, and 35 miles per hour during periods in the storms when rain is falling heavily and after the foliage has been wet for some time.

While it has not been determined, it is most probable, all things being considered, that the distance of splash will vary directly with the wind velocity. If water is splashed 18 feet by a wind blowing 10 miles per hour, it will splash approximately 50 feet at 30 miles per hour.

The elevation of the surface of impact in the experiment in which the effect of the wind was observed was 3 feet, and this is entirely within the range of the height of cotton leaves, many being higher than this during the latter half of the season. It is shown in Table III that the splash drops from the 0.02-c. c. drop falling 16 feet reach their maximum distance at this elevation in a still atmosphere.

CONCLUSIONS

It has been shown by experiment that water is splashed by a falling drop only when it falls upon a film of water, and it is the water of the film which composes the splash drops. The distance of the splash varies according to the size of drop, depth of surface films, elevation and inclination of surface of impact, and the velocity of the wind. Field conditions have been duplicated with sufficient accuracy to justify the con-

[1] FAULWETTER, R. C. Op. cit., p. 465.

clusion that these facts hold true in the field during any rainfall; and, in view of my previous experiments showing the emanation of motile bacteria from lesions into the surface water film, their dissemination is the natural result.

It was stated in the paper cited above[1] that—

> unless a great amount of this spread took place at one time, it would have been difficult to understand how the disease could progress so far in one direction if each spot took 8 to 10 days to appear.

And the second inoculation experiment in which bacteria were used which had never been in culture failed to clear the question. The data presented here, however, show that it was entirely possible for most of the spread to have taken place at one time, though no records of wind velocity during the two thunderstorms of June, 1916, are available.

In the experiment in which the effect of the wind was studied all the factors were within the limits of field conditions. A drop of 0.02 c. c. in volume falling 16 feet upon a relatively thin film of water which was splashed, as is proved by the acetic-acid distribution, upon a plate 3 feet above the floor during a wind of 10 miles an hour, splashed water in abundance a distance of 8 feet (across two rows of cotton) in moderate quantities as far as 12 feet (three rows) and in slight amounts to 16 feet. To quote again from the former paper:[2]

> The possibilities of this chain of action during a driving rain are considerable if one includes the distance bacteria may be carried from the original lesion, then splashed up again and carried farther, and so on, until a dilution too great for infection is obtained.

Local dissemination of such diseases as described by Rolfs, Pierce, and others is well within the limits of probability in the presence of dew and heavy fogs without wind. Each drop (the drops from leaves are larger than the average raindrops) falling 12 inches upon a film of water will scatter splash drops over an area of 20 to 32 inches in diameter. The rapidity with which local dissemination of such diseases takes place is easily accounted for.

One could well expand this discussion to include the applications of these conclusions to other similar diseases, but, since no opportunity has been had to study the conditions under which such dissemination must take place, this phase is omitted for the present. However, one can readily understand the possibilities if he takes into consideration the increase of extreme distance of splash due to greater elevation of surface of impact as would occur in pear, walnut, and Citrus trees and greater wind velocity, as occurs in typical thunderstorms of this region and especially during the hurricanes frequent in the southeastern Citrus regions.

[1] FAULWETTER, R. C. Op. cit., p. 467. [2] Idem, p. 470.

INDEX

Page

Acer rubrum—
character of trees of attacked by *Agromyza aceris* ... 313
description of *Agromyza aceris* in ... 313, 315, 316
host of *Agromyza aceris* ... 313–318
Acetaldehyde, toxicity to insects ... 367, 370
Acetic acid. See Acid, acetic.
Acetone, toxicity to insects ... 367, 370
Acid—
acetic—
titrations of sodium nitrate-calcium carbonate solution with ... 551
toxicity to insects ... 367, 370
amino, percentage of groups in animal proteins ... 635
carbonic—
in alkali ... 342–344, 349, 352
in ash ... 340–341, 349, 352
in gypsum ... 350
in sandstone ... 337, 344–345, 349, 352
in shale ... 338–340, 349, 352
in soil ... 341, 343–344, 348
cyanuric—
comparison with tetracarbonimid ... 87–88
isolation from soil ... 85–92
hydrochloric, titrations of sodium chloride-calcium carbonate solutions with ... 554
mineral, effect on reproduction of cattle ... 186–187
nitric, titrations of sodium nitrate-calcium carbonate solution with ... 554
oxalic, titrations of sodium nitrate-calcium carbonate solutions with ... 552–553
percentage in alfalfa silage ... 276, 278, 284–285, 287, 291
production of, in silage ... 75–83
sulphuric—
in alkali ... 342–344, 349, 352
in ash ... 340–341, 349, 352
in gypsum ... 350
in sandstone ... 337, 344–345, 349, 352
in shale ... 338–340, 349, 352
in soil ... 341, 348
titrations of sodium sulphate-calcium carbonate solutions with ... 554
toxicity to insects ... 367, 368, 370
valeric, toxicity to insects ... 367, 368, 370
Aggregate—
bituminous—
effect of surface character of rock on ... 328
physical tests ... 328
toughness ... 329–330
effect of grading on value ... 265–274
Agromyza—
aceris—
character of trees attacked by ... 313
n. sp ... 313, 315, 316
parasite of *Acer rubrum* ... 313–318
amelanchieris—
character of trees attacked by ... 313
n. sp ... 314
parasite of *Amelanchier canadensis* ... 313–318
seasonal history ... 314, 315, 317

Page

Alcohol, toxicity to insects ... 367, 369, 370
Alfalfa. See *Medicago sativa*.
Alfalfa silage. See Silage, alfalfa.
Alkali—
black—
effect of hardpan on formation ... 586–588
formation ... 541–590
See also Sodium carbonate.
crusts in irrigated regions ... 578–580
formation by soluble salts ... 334–352
origin ... 331–353
soluble salts in ... 342–344, 347, 352
Allard, H. A. (paper): Further Studies of the Mosaic Disease of Tobacco ... 615–632
Alway, F. J., and McDole, G. R. (paper): Relation of Movement of Water in a Soil to Its Hygroscopicity and Initial Moistness ... 391–428
Allyl isosulphocyanate, toxicity to insects ... 367, 368, 370
Amelanchier canadensis, host of *Agromyza amelanchieris* ... 313–318
Amino acid. See Acid, amino.
Amino nitrogen, in alfalfa silage ... 286–287, 290
Ammonia, effect of paraffin on ... 355–363
Amyl—
acetate, toxicity to insects ... 367, 368, 370
alcohol, toxicity to insects ... 367, 370
nitrite, toxicity to insects ... 367, 370
valerate, toxicity to insects ... 367, 368, 370
Andropogon sorghum—
variation of dry matter in leaves ... 11–46
variation of water in leaves ... 11–46
Angitia plutellae—
host of *Spilochalcis delira* ... 8
parasite of *Plutella maculipennis* ... 8
Animal proteins, food value ... 633–637
Antirrhinum spp., host plant of *Tarsonemus pallidus* ... 377
Aphis—
chrysanthemum. See *Macrosiphum sanborni*.
effectiveness of quassia extract on ... 497–531
pear-root, European. See *Eriosoma lanuginosa*.
spinach. See *Myzus persicae*.
woolly pear. See *Eriosoma pyricola*.
Armsby, H. P., and Fries, J. A. (paper): Energy Values of Hominy Feed and Maize Meal for Cattle ... 599–613
Arsenate—
calcium—
burning effect of spray on plant ... 206
toxicity ... 199–207
lead, toxicity ... 199–207
lead hydrogen, toxicity ... 199–207
Ash—
alkali in ... 344, 352
soluble salts in ... 340–341, 346, 352
Avena sativa nuda × *Avena sativa patula*, crossing experiments ... 293–312
Avena sativa patula × *Avena sativa nuda*, crossing experiments ... 293–312

Bacteria— Page
cause of heat production in silage..... 77
probable cause of new disease of *Triticum* spp..... 52
Baker, A. C., and Davidson, W. N. (paper): A Further Contribution to the Study of Eriosoma pyricola, the Woolly Pear Aphis..... 65–74
Barberry. See *Berberis* spp.
Barren spots, origin..... 580–582
Benzene, toxicity to insects..... 367, 369, 370
Berberis spp., relation to rust epidemics.... 489–491
Berry, service. See *Amelanchier canadensis*.
Biologic Forms of Puccinia graminis on Cereals and Grasses (paper)..... 429–496
Bituminous aggregates. See Aggregates, bituminous.
Black Rootrot of the Apple (paper)..... 163–174
Black rootrot. See Rootrot, black.
Blatella germanica, effect of nicotine sulphate on..... 48
Blight—
needle, description..... 100
nursery, of *Juniperus* spp.—
control..... 538–539
description..... 534–536
distribution..... 535–536
history..... 533–534
Borax, effect on *Triticum* spp. of manure treated with..... 591–597
Boron, effect on *Triticum* spp..... 591–597
Brassica—
juncea, host plant of *Plutella maculipennis*. 3
napus, host plant of *Plutella maculipennis*. 3
nigra, host plant of *Plutella maculipennis*.. 3
oleracea—
acephala, host plant of *Plutella maculipennis*..... 3
botrytis, host plant of *Plutella maculipennis*..... 3
capitata, inoculation with Colletotrichum leafspot fungus..... 158
caulo-rapa, host plant of *Plutella maculipennis*..... 3
viridis, inoculation with Colletotrichum leafspot fungus..... 158
rapa—
host of Colletotrichum leafspot fungus. 157–162
identification of causal organism of Colletotrichum leafspot..... 160–161
Breazeale, J. F. (paper): Formation of "Black Alkali" (Sodium Carbonate) in Calcareous Soils..... 541–590
Bromcresol purple, substitute for litmus for use in milk culture..... 105–111
Brometone, toxicity to insects..... 368, 370
Bromid, ethylene, toxicity to insects.. 367, 368, 370
Brommethylphenylketone, toxicity to insects..... 367, 370
Bromoform, toxicity to insects..... 367, 368, 370
Butyric acid, toxicity to insects..... 367, 368, 370

Cabbage. See *Brassica oleracea capitata*.
Calcium—
arsenate—
burning effect of spray on plant..... 206
toxicity..... 199–207
Calcium—Continued Page
carbonate—
effect of paraffin on..... 355–363
effect of sodium salts upon solubility of in soils..... 577–578
reaction with sodium—
chlorid and calcium chlorid..... 547
nitrate and calcium nitrate..... 547
nitrate and calcium sulphate..... 549
salts..... 543–546, 566
salts and carbon dioxid..... 558–560
sulphate and calcium sulphate..... 547, 550
chlorid, reaction with sodium chlorid and calcium carbonate..... 547
in alkali..... 342–344, 349, 352
in ash..... 340–341, 349, 352
in gypsum..... 350
in sandstone..... 337, 344–345, 349, 352
in shale..... 338–340, 349, 352
in soil..... 341, 343–344, 348
nitrate, reaction with sodium nitrate and calcium carbonate..... 547
sulphate, reaction with—
sodium chlorid and calcium carbonate... 549
sodium nitrate and calcium carbonate... 549
sodium sulphate and calcium carbonate. 547, 550
Cambium miner. See *Agromyza aceris*.
Camphene, toxicity to insects..... 367, 368, 369, 370
Camphor, toxicity to insects..... 368, 370
Candytuft. See *Iberis amara*.
Carbon—
bisulphid, toxicity to insects..... 367, 369, 370
dioxid, reaction with sodium salts and calcium carbonate..... 558–560
tetrachlorid, toxicity to insects 367, 368, 370
Carbonic acid. See Acid, carbonic.
Caterpillar. See *Malacosoma pluvialis*.
Cattle—
correctives for whole-wheat feeding..... 190–192
energy values of feed for..... 559–613
growth, effect of vitamines on..... 187–189
growth on corn rations..... 176–180
growth on wheat rations..... 178–180
milk secretion of, effect of—
baked wheat on..... 183–184
mineral acids added to corn ration on.. 186–187
raw flour on..... 183–184
salts added to imperfect ration..... 180–183
various rations on..... 178–180, 191–192
vitamines with wheat ration on..... 187–189
wheat embryo on..... 189–192
reproduction of, effect of—
baked wheat on..... 183–184
balanced rations on..... 176–180
imperfect rations..... 176–180
mineral acids added to a corn ration on. 186–187
raw flour on..... 183–184
salts added to corn ration..... 184–185
salts added to imperfect rations..... 180–183
vitamines with wheat ration on..... 187–189
wheat embryo on..... 189–192
Cauliflower. See *Brassica oleracea botrytis*.
Cedar—
blight. See Blight, cedar.
red. See *Juniperus virginiana* and *J. scopulorum*.

Page

Cement, concrete, effect of grading of aggregates on 263-274
Cereals, occurrence of biologic forms of *Puccinia graminis* on 429-496
Chemical Studies in Making Alfalfa Silage (paper) 275-292
Chloral hydrate, toxicity to insects 367, 368, 370
Chloretone, toxicity to insects 368, 370
Chlorin in—
  alkali 342-344, 347, 349, 352
  ash 340-341, 349
  gypsum 350
  sandstone 337, 344-345, 349
  shale 338-340, 348-349
  soil 341-342, 348
Chloroform, toxicity to insects 367, 368, 370
Chlorpicrin, toxicity to insects 367, 369, 370
Chrysanthemum—
  aphis. See *Macrosiphum sanborni.*
  host plant of *Tarsenomus pallidus* 377
Citral, toxicity to insects 367
Clark, W. M., and Lubs, H. A. (paper): A Substitute for Litmus for Use in Milk Cultures 105-111
Clay, soluble salts in 341-342, 348, 352
Colemanite, effect on *Triticum* spp. of manure treated with 591-597
Collard. See *Brassica oleracea viridis.*
Colletotrichum—
  brassicae, mistaken for causal organism of Colletotrichum leafspot 160-161
  higginsianum—
    causal organism of leafspot of *Brassica rapa* (footnote) 161
    n. sp. (footnote) 161
Colletotrichum Leafspot of Turnips, A (paper) 157-162
Concrete—
  bituminous, index to service 328
  cement, effect of grading of aggregates on. 263-274
Cook, F. C., and Wilson, J. B. (paper): Effect of Three Annual Applications of Boron on Wheat 591-597
Corn—
  influence on alfalfa silage 280
  See also *Zea mays.*
Crop, effect on soil moisture 117-124, 151
Croton bug. See *Blatella germanica.*
Cultivation, effect on soil moisture. 115, 128-129, 151
Culture, milk, use of bromcresol purple in. 105-111
Cupressus glabra, host of *Phoma* sp 538
Cyanuric acid. See Acid, cyanuric.
Cyclamen Mite, The (paper) 373-390
  See also *Tarsonemus pallidus.*
Cylindrosporium brassicae, comparison with causal organism of Colletotrichum leafspot 161-162

Daily Variation of Water and Dry Matter in the Leaves of Corn and the Sorghums (paper) 11-46
Davenport, C. B., and Ritzman, E. G. (paper): Family Performance as a Basis for Selection in Sheep 93-97
Davidson, W. M., and Baker, A. C. (paper): A Further Contribution to the Study of Eriosoma pyricola, the Woolly Pear Aphis. 65-74

Page

Diamond-Back Moth. See *Plutella maculipennis.*
Dibromoorthocresolsulfonphthalein. See Bromcresol purple.
Digestion, influence of—
  moisture of feces of steer on 55-56
  rate of passage of feed through the steer on. 60-61
Disease dissemination by wind-blown rain. 639-648
Douglas fir. See *Pseudotsuga taxifolia.*

Effect of Paraffin on the Accumulation of Ammonia and Nitrates in the Soil (paper) 355-363
Effect of Three Annual Applications of Boron on Wheat (paper) 591-597
Embryo, wheat, effect on reproduction in cattle 189-190
Elm. See *Ulmus* spp.
Energy—
  chemical, losses 604-605, 607
  metabolizable—
    losses 604-605
    values of feed 609-610
  net, values of feed 607-608
Energy Values of Hominy Feed and Maize Meal for Cattle (paper) 599-613
Eriosoma—
  lanuginosa, comparison with *Eriosoma pyricola* 66-68
  pyri, alternate form of *Eriosoma lanuginosa*. 66
  pyricola—
    comparison with *Eriosoma lanuginosa* ... 66-68
    description 67-68
    life history 68-73
    parasite of—
      Pyrus communis 65-74
      Ulmus americana 68
      Ulmus campestris 68
Errata IV
Ether—
  solvent of quassiin powder 510-511
  toxicity to insects 367, 369, 370
Ethyl—
  acetoacetate, toxicity to insects 367, 368, 370
  alcohol, toxicity to insects 367, 369, 370
  ether, toxicity to insects 367, 370
  malonate, toxicity to insects 367, 368, 370
  mercaptan, toxicity to insects 367, 369, 370
Ethylene bromid, toxicity to insects ... 367, 368, 370
Eugenol, toxicity to insects 367
Evaporation—
  accuracy of measurements for 216-217
  analysis of river-bed materials for 244-249
  description of tanks used for 249
  effect of—
    depth on 218-238
    flowing water on 227-229
    on irrigation 209
    size of water surfaces on 218-259
    still water on 227-229
    stream-bed materials on 242-259
    temperature on 218-239, 253
    weather on 241-242
    wind velocity on 239-241
Evaporation from the Surfaces of Water and River-Bed Materials (paper) 209-261
Ewing, P. V., and Smith, F. H. (paper): A Study of the Rate of Passage of Food Residues through the Steer and Its Influence on Digestion Coefficients 55-63

Page

Fallow soil. See Soil, fallow.
Family Performance as a Basis for Selection in Sheep (paper)..... 93-97
Faulwetter, R. C. (paper): Wind-blown Rain, A Factor in Disease Dissemination..... 639-648
Feces, steer, relation of moisture content of, on digestion coefficients..... 55-56
Feed—
  effect on—
    growth of cattle..... 175-198
    milk secretion in cattle..... 179-198
    reproduction of cattle..... 175-198
  energy values..... 599-613
  influence of—
    kind on rate of passage through steer.... 60
    quantity on rate of passage through steer. 60, 61
    rate of passage through steer on digestion. 55-63
Fertilizer. See Manure.
Fir, Douglas. See *Pseudotsuga taxifolia*.
Food, value of proteins of insects as..... 633-637
Food plants, effect of nicotine sulphate as spray on..... 47-50
Formation of "Black Alkali" (Sodium Carbonate) in Calcareous Soils (paper)..... 541-590
Fries, J. A., and Armsby, H. P. (paper): Energy Values of Hominy Feed and Maize Meal for Cattle..... 599-613
Fromme, F. D., and Thomas, H. E. (paper): Black Rootrot of the Apple..... 163-174
Fungus—
  cause of Colletotrichum leafspot of *Brassica rapa*..... 157-162
  needle-blight—
    control..... 102
    description..... 102-103
    distribution..... 99, 101-102
    effect of season on dissemination..... 100-101
    identification..... 102-103
    parasite of *Pseudotsuga taxifolia*..... 99-103
Furfural, toxicity to insects..... 367, 370
Further Contribution to the Study of Eriosoma pyricola, the Woolly Pear Aphis, A (paper)..... 65-74
Further Studies of the Mosaic Disease of Tobacco (paper)..... 615-632

Gainey, P. L. (paper): Effect of Paraffin on the Accumulation of Ammonia and Nitrates in the Soil..... 355-363
Gall aphis. See *Eriosoma pyricola*.
Gasoline, toxicity to insects..... 367, 369, 370
Graham, S. A., and Moore, W. (paper): A Neglected Factor in the Use of Nicotine Sulphate as a Spray..... 47-50
Grasses—
  occurrence of biologic forms of *Puccinia graminis* on..... 429-496
  wild, relation to rust epidemics..... 488-491
Grasshopper. See *Melanoplus* spp.
Gravity, effect on soil moisture. 117, 131-143, 150, 151
Greene, C. T. (paper): Two New Cambium Miners (Diptera)..... 313-318
Gypsum—
  chlorin in..... 350
  effect upon formation of sodium carbonate..... 549-550
  soluble salts in..... 350

Page

Hahn, G. G., Hartley, C., and Pierce, R. G. (paper): A Nursery Blight of Cedars..... 533-540
Harris, F. S., and Turpin, H. W. (paper): Movement and Distribution of Moisture in the Soil..... 113-155
Hart, E. B., McCollum, E. V., Steenbock, H., and Humphrey, G. C. (paper): Physiological Effect on Growth and Reproduction of Rations Balanced from Restricted Sources..... 175-198
Hartley, C., et al. (paper): A Nursery Blight of Cedars..... 533-540
Hay, clover and timothy, digestibility..... 603-604
Heat production—
  in silage..... 75-83
  in cattle..... 605-607
Hexane. See Petroleum ether.
Higgins, B. B. (paper): A Colletotrichum Leafspot of Turnips..... 157-162
Hominy feed—
  composition..... 600
  digestibility..... 603-604, 610, 611
  energy values..... 599-613
Horse fly. See *Musca domestica*.
Horse-radish. See *Radicula armoracea*.
Humphrey, G. C., et al. (paper): Physiological Effect on Growth and Reproduction of Rations Balanced from Restricted Sources..... 175-198
Hunter, O. W. (paper): Microorganisms and Heat Production in Silage Fermentation... 75-83
Hydrochloric Acid. See Acid, hydrochloric.
Hygroscopicity, relation of soil-water movement to..... 391-428

Iberis amara, host plant of *Plutella maculipennis*..... 3
Influence of Grading on the Value of Fine Aggregate Used in Portland Cement Concrete Road Construction (paper)..... 263-274
Insect—
  proteins, food value of..... 633-637
  toxicity of arsenates to..... 199-207
  toxicity of organic compounds to..... 365-371
Insecticide, quassia extract as..... 497-531
Irrigation, distribution of soil moisture after. 116, 117-118, 120-127, 133-134
Isoeugenol, toxicity to insects..... 367
Isolation of Cyanuric Acid from Soil (paper). 85-92

Jackson, jr., F. H. (paper): Influence of Grading on the Value of Fine Aggregate Used in Portland Cement Concrete Road Construction..... 263-274
June bug. See *Lachnosterna* sp.
Juniperus—
  barbadensis, host of *Phoma* sp..... 538
  communis, host of *Phoma* sp..... 538
  pachyphloea, host of *Phoma* sp..... 538
  prostrata, host of *Phoma* sp..... 538
  scopulorum, host of *Phoma* sp..... 533-540
  spp.—
    nursery-blight of—
      control..... 538-539
      description..... 534-536
      distribution..... 535-536
      history..... 533-534
  virginiana, host of *Phoma* sp..... 533-540

Page

Kafir. See *Andropogon sorghum.*
Kale. See *Brassica oleracea acephala.*
Kerosene, toxicity to insects..... 368, 369, 370
Kohlrabi. See *Brassica oleracea caulo-rapa.*
Koniga maritima, host plant of *Plutella maculipennis*..... 3

Lachnosterna sp., value of as food for poultry 634–637
Lactuca sativa—
  effect of nicotine sulphate on..... 47–50
  inoculation with Colletotrichum leafspot fungus..... 158
Lead arsenate, toxicity..... 199–207
Lead hydrogen arsenate, toxicity..... 199–207
Leafspot, Colletotrichum—
  causal organism—
    comparison with *Cylindrosporium brassicae.*
    description (footnote)..... 161
    identification..... 160–161
    inoculation of plants with..... 158–159
    See also *Colletotrichum higginsianum.*
    seed infection..... 159–160
  description..... 157
Leaf, water content..... 11–45
Lettuce. See *Lactuca sativa.*
Lewis, R. H., and Reeve, C. S. (paper): Toughness of Bituminous Aggregates.... 319–330
Life History of Plutella maculipennis, the Diamond-Back Moth (paper)..... 1–10
Lime—
  effect of hardpan of upon formation of black alkali..... 586–588
  salts of, effect upon formation of sodium bicarbonate..... 561–562
  solubility..... 565
  soluble salts of—
    effect upon formation of sodium carbonate..... 547–549
    formation of sodium carbonate in presence of..... 550–557
  insoluble salts of, formation of sodium carbonate in presence of..... 550–557
Litmus, use of bromcresol purple as substitute for..... 105–111
Louse, plant. See Macrosiphum.
Lovett, A. L., and Robinson, R. H. (paper): Toxic Values and Killing Efficiency of the Arsenates..... 199–207
Lubs, H. A. and Clark, W. M. (paper): A Substitute for Litmus for Use in Milk Cultures..... 105–111

Macrosiphum—
  lactucae, transmission of mosaic disease by 627–628
  pelargonii, transmission of mosaic disease by 628
  sanborni, effect of nicotine sulphate on..... 49
  tabaci, transmission of mosaic disease by..628–629
Magnesium in—
  alkali..... 342–344, 349, 352
  ash..... 340–341, 349, 352
  gypsum..... 350
  sandstone..... 337, 344–345, 348, 349, 352
  shale..... 338–340, 349, 352
  soil..... 341, 342, 343–344, 348
Maize. See *Zea mays.*

Page

Maize meal, digestibility..... 603–604
Malacosoma pluvialis, effect of arsenic on.. 199–207
Malus sylvestris, host of *Xylaria* spp..... 163–174
Manure—
  effect on soil moisture..... 115, 120–125, 151
  treated with—
    borax, effect on *Triticum* spp..... 591–597
    colemanite, effect on *Triticum* spp..... 591–597
Maple, red. See *Acer rubrum.*
Marsh, H. O. (paper): Life History of Plutella maculipennis, the Diamond-Back Moth... 1–10
McCollum, E. V., et al (paper): Physiological Effect on Growth and Reproduction of Rations Balanced from Restricted Sources. 175–198
McDole, G. R., and Alway, F. J. (paper): Relation of Movement of Water in a Soil to Its Hygroscopicity and Initial Moistness. 391–428
McHargue, J. S. (paper): A Study of the Proteins of Certain Insects with Reference to their Value as Food for Poultry..... 633–637
McIndoo, N. E., and Sievers, A. F. (paper:) Quassia Extract as a Contact Insecticide. 497–531
Medicago sativa—
  chemical studies in making silage..... 275–292
  effect on—
    growth of cattle..... 177–197
    milk secretion of cattle..... 179–197
    reproduction of cattle..... 179–197
Melanoplus spp., value of as food for poultry 634–637
Menthol, toxicity to insects..... 368, 370
Menthone, toxicity to insects..... 367, 368, 370
Mesochorus sp., parasite of *Plutella maculipennis*..... 8
Meteorus sp., parasite of *Plutella maculipennis* 8
Methyl alcohol, toxicity to insects..... 367, 369, 370
Methyl salicylate, toxicity to insects... 367, 368, 37
Microorganisms and Heat Production in Silage Fermentation (paper)..... 75–83
Microplitis sp., parasite of *Plutella maculipennis*..... 8
Milk—
  secretion in cattle—
    effect of baked wheat on..... 183–184
    effect of mineral acids on..... 186–187
    effect of raw flour on..... 183–184
    effect of salts on..... 180–185
    effect of various rations on..... 178–180, 191–192
    effect of wheat embryo on..... 189–192
    influence of salts added to imperfect ration..... 180–183
  use of bromcresol purple in cultures of .. 105–111
Miller, E. C. (paper): Daily Variation of Water and Dry Matter in the Leaves of Corn and the Sorghums..... 11–46
Milo. See *Andropogon sorghum.*
Miner, cambium. See *Agromyza aceris.*
Mite, cyclamen. See *Tarsonemus pallidus.*
Moisture—
  in alfalfa silage..... 286–287, 290
  initial—
    relation of soil water movement to..... 391–428
    relation to hygroscopic coefficient..... 406–408
  See also Water.
  soil, forces acting on..... 114–153
  steer, feces, relation to digestion coefficients. 55–56
Molasses, influence on alfalfa silage..... 280

Page

Moore, W. (paper): Volatility of Organic Compounds as an Index of the Toxicity of their Vapors to Insects 365-371
Moore, W., and Graham, S. A. (paper): A Neglected Factor in the Use of Nicotine Sulphate as a Spray 47-50
Mortar, sand, effect of grading on—
compression of 271-274
hardness of 267-269
tension of 271-274
toughness of 270-271
Mosaic disease—
control 621-623, 627, 629
distribution of virus in *Nicotiana tabacum* 620-621
effect of soil sterilization on 622-623
effect of washing on removal of virus of from hands 621-622
effect on *Nicotiana glauca* 624-626
resistance of *Nicotiana tabacum* to 618-620
transmission by plant lice 626-630
Movement and Distribution of Moisture in the Soil (paper) 113-155
Moznette, G. F. (paper): The Cyclamen Mite 373-390
Mulch, effect on soil moisture 125-128, 152
Musca domestica, toxicity of organic compounds to 365-371
Mustard—
Chinese. See *Brassica juncea*.
hedge. See *Sisymbrium* sp.
See also *Brassica nigra*.
Myzus persicae—
effect of nicotine sulphate on 49
transmission of mosaic disease by 626-630

Naphthalene, toxicity to insects 367-370
Needle-blight, description 100
Needle-blight fungus. See Fungus, needle-blight.
Needle Blight of Douglas Fir, A (paper) 99-104
Neglected Factor in the Use of Nicotine Sulphate as a Spray, A (paper) 47-50
New Disease of Wheat, A (paper) 51-54
Nicotiana—
glauca, effect of Mosaic disease on 624-626
tabacum—
control of mosaic disease on 623, 627, 629
distribution of virus of mosaic disease in 620-621
infectivity of virus of mosaic disease on 615-631
resistance to mosaic disease 618-620
transmission of mosaic disease by plant lice 626-630
Nicotine, toxicity to insects 367, 368, 370
Nicotine sulphate—
as spray—
comparison with nicotine 47-50
effect on *Macrosiphum sanborni* 49
effect on *Myzus persicae* 49
poisoning by 47-50
toxicity to man 47
effectiveness of quassia extracts containing 515-518
effect of alkali on 48-50
effect on *Blatella germanica* 48
nonvolatility 48-50

Page

Niter spots, soluble salts in 343-344
Nitrate, effect of paraffin on 355-363
Nitric acid. See Acid, nitric.
Nitrobenzene, toxicity to insects 367, 368, 370
Nitrogen—
amino, in alfalfa silage 286-287, 290
ammonia, effect of paraffin on 355-363
effect of paraffin on 355-363
Nursery Blight of Cedars, A (paper) 533-540

Oat—
hulled. See *Avena sativa patula*.
naked. See *Avena sativa nuda*.
Organic compounds—
index of toxicity to insects 365-371
relation of volatility to toxicity 365-371
Origin of Alkali (paper) 331-353
Oxalic acid. See Acid, oxalic.

Packing, influence on alfalfa silage 278, 280
Paraffin, effect on ammonia nitrogen 355-363
Pear aphis, woolly. See Aphis, woolly pear.
Pear. See *Pyrus communis*.
Pentane. See Petroleum ether.
Peterson, W., and Stewart, R. (paper): Origin of Alkali 331-353
Petroleum ether, toxicity to insects 367, 369, 370
Phoma sp., causal organism of nursery blight of cedars 533-540
Physiological Effect on Growth and Reproduction of Rations Balanced from Restricted Sources (paper) 175-19
Piemeisel, F. J., and Stakman, E. C. (paper): Biologic Forms of Puccinia graminis on Cereals and Grasses 429-496
Pierce, R. G., et al. (paper): A Nursery Blight of Cedars 533-540
Pinene, toxicity to insects 367, 369
Plutella maculipennis—
control 9
description 1-2
distribution 2-3
egg laying 7-8
generations 5-6
host plants 3
injury to plants 8
life history 4-8
natural enemies 8
seasonal history 3-4
Poisoning—
insect, relation of volatility of organic compounds to 365-371
nicotine 47-50
Poultry, value of proteins of insects as food for 633-648
Propyl acetate, toxicity to insects 367, 368, 370
Protein—
animal, percentage of amino-acid groups in 634-635
insect, value as food 633-637
Pseudotsuga taxifolia—
control of needle-blight fungus on 102
description of needle-blight fungus on 102-103
distribution of needle-blight fungus on 99, 101-102
food plant of needle-blight fungus 99-103
identification of needle-blight fungus on 102-103

Puccinia graminis— Page
appearance of uredinia ... 486–487
development of uredinia ... 486–487
identity ... 429–493
infection of cereals by ... 429–493
morphology of urediniospores ... 484–488
on cereals ... 429–493
on grasses ... 429–493
parasitism ... 488
relation of wild grasses to ... 488–491
results of inoculation of urediniospores on various hosts ... 432–484
Pyridin, toxicity to insects ... 367, 370
Pyrus communis, host plant of *Eriosoma pyricola* ... 65–74

Quassia—
effectiveness of—
extracts ... 502–504
spray solutions ... 515–516
effect of—
boiling chips on extraction of ... 503–504
fineness of chips on extraction of ... 506
size of chips on extraction of ... 504
quantity of water on extraction of ... 507
preparation of extract ... 502–503
Quassia Extract as a Contact Insecticide (paper) ... 497–531
Quassiin—
pharmacological effects ... 518–526
solubility ... 509–510

Radicula—
armoracea, host plant of *Plutella maculipennis* ... 3
sinuata, host plant of *Plutella maculipennis* ... 3
Radish. See *Raphanus sativus*.
Rain, factor in disease dissemination ... 639–648
Rape. See *Brassica napus*.
Raphanus sativus—
host plant of *Plutella maculipennis* ... 3
inoculation with Collectotrichum leafspot fungus ... 158
Reeve, C. S. and Lewis, R. H. (paper): Toughness of Bituminous Aggregates ... 319–330
Relation of Movement of Water in a Soil to Its Hygroscopicity and Initial Moistness (paper) ... 391–428
Reproduction, cattle, effect of various rations on ... 175–198
Ritzman, E. G., and Davenport, C. B. (paper): Family Performance as a Basis for Selection in Sheep ... 93–97
Robinson, R. H., and Lovett, A. L. (paper): Toxic Values and Killing Efficiency of the Arsenates ... 199–207
Rock—
country, alkali material in ... 352
effect of surface character on bituminous aggregates ... 328
hardness ... 264–265
physical tests ... 320, 323, 326
soluble salts in ... 349–350
toughness ... 264–265, 319–330
Rootrot, black—
association with other fungi ... 165–167
control ... 170–171

Rootrot, black—Continued Page
distribution ... 163
losses ... 163
symptoms ... 163–165
Roripa sinuata, host plant of *Plutella maculipennis* ... 3
Rust—
cereal, origin of spring infection by ... 429–493
infection of grasses by ... 429–493
See also *Puccinia graminis*.
timothy—
biologic form of *Puccinia graminis* ... 433
distribution ... 482
Rye, influence on alfalfa silage ... 280

Salts—
effect on milk secretion of cattle ... 180–185
effect on reproduction of cattle ... 180–185
sodium, reaction between calcium carbonate and ... 543–546
soluble—
cause of formation of alkali ... 334–352
in alkali ... 342–344, 347, 352
in ash ... 340–341, 346, 352
in gypsum ... 350
in niter spots ... 343–344
in sandstone ... 336–338, 344–345, 352
in shale ... 338–340, 352
in soil ... 341–342, 348
Sand, effect of grading on—
compression of mortar ... 271–274
hardness of mortar ... 267–269
tensile strength of mortar ... 273
tension of mortar ... 271–274
toughness of mortar ... 270–271
Sandstone, soluble salts in ... 336–338, 344–345, 349, 352
Seed, infection by Colletotrichum leafspot fungus ... 159–160
Service berry. See *Amelanchier canadensis*.
Shadbush. See *Amelanchier canadensis*.
Shale—
alkali in ... 344, 352
soluble salts in ... 338–340, 345, 348–349, 352
Sheep, family performance as a basis of selection in ... 93–97
Sievers, A. F., and McIndoo, N. E. (paper): Quassia Extract as a Contact Insecticide ... 497–531
Silage, alfalfa—
acidity ... 276, 278, 284–285, 287, 291
amino nitrogen in ... 286–287, 290
chemical analysis ... 281–283, 288–290
influence of—
corn on ... 280
maturity on ... 277
moisture ... 276, 278, 283, 290
molasses on ... 280
packing on ... 278, 280
rye on ... 280
wilting on ... 278–279
percentage of sugar in ... 291
quality ... 276, 277, 279–280
Silage, heat production in ... 75–83
Sisymbrium sp., host plant of *Plutella maculipennis* ... 3
Sleight, R. B. (paper); Evaporation from the Surfaces of Water and River-Bed Materials ... 209–261
"Slick" spots, origin ... 580–582

Page

Smith, E. F. (paper): A New Disease of Wheat 51-54
Smith, F. H., and Ewing, P. V. (paper): A Study of the Rate of Passage of Food Residues through the Steer and Its Influence on Digestive Coefficients 55-63
Snapdragon. See *Antirrhinum* spp.
Soap, effectiveness as insecticide of quassia extracts containing 515
Sodium—
  bicarbonate—
    effect of soluble lime salts upon formation of 561-562
    effect upon organic matter 575
  carbonate—
    effect of—
      gypsum upon formation of 549-550
      reaction of calcium carbonate on 543-546
      soluble lime salts upon formation of. 547-549
    effect upon organic matter in soil 566-572, 575-577
    formation in presence of salts of lime ... 550-557
    See also Alkali, black.
  chlorid—
    effect upon organic matter of soil in presence of sodium carbonate 582-586
    reaction with—
      calcium carbonate and calcium chlorid. 547
      calcium carbonate and calcium sulphate 549
      sodium sulphate and calcium carbonate 75
  in alkali 342-344, 349, 352
  in ash 342-344, 352
  in shale 342-344, 349, 352
  in soil 342-344, 352
  nitrate, reaction with—
    calcium carbonate 545
    calcium carbonate and calcium nitrate ... 547
    calcium carbonate and calcium sulphate. 549
  salts—
    effect upon solubility of calcium carbonate in soils 577-578
    reaction with—
      calcium carbonate 543, 566
      calcium carbonate in presence of carbon dioxid 558-560
  sulphate—
    effect upon organic matter of soil in presence of sodium carbonate 582-586
    reaction with—
      calcium carbonate 546
      calcium carbonate and calcium sulphate 547, 550
      sodium chlorid and calcium carbonate. 549
Soil—
  alkali in 344
  analysis of, for use in evaporation experiment 244-249
  calcareous, formation of black alkali in .. 541-590
  effect of—
    boron in, on *Triticum* spp. 591-597
    paraffin on—
      ammonia in 355-363
      ammonia nitrogen in 356-363
      calcium carbonate in 355-363
      nitrate in 355-363

Page

Soil—Continued
  effect of—Continued
    sodium—
      chlorid upon organic matter of in presence of sodium carbonate 582-586
      salts upon solubility of calcium carbonate in 577-578
      sulphate upon organic matter of in presence of sodium carbonate 582-586
  fallow, effect on soil moisture 117-124, 151
  isolation of cyanuric acid from 85-92
  moisture. See Moisture, soil.
  relation between sodium salts and calcium carbonate in 566
  relation of mosaic disease to infection in .. 623-624
  soluble salts in 341-342, 346, 348, 349, 350, 352
  sterilization, effect on mosaic disease 622-623
  type, effect on soil moisture 116, 143-153
  water movement in, in relation to—
    hygroscopicity 391-428
    initial moistness 391-428
Sorghum. See *Andropogon sorghum*.
Species, new ..... 161 (footnote), 313-316
Specific gravity, apparent, relation to—
  hygroscopicity 409
  moistness 409
Spilochalis deliva, parasite of *Angitia plutellae*. 8
Spray—
  effect of arsenates as 199-207
  use of nicotine sulphate as 47-50
Stakman, E. C., and Piemeisel, F. J. (paper): Biologic Forms of Puccinia graminis on Cereals and Grasses 429-496
Steenbock, H., et al. (paper): Physiological Effect on Growth and Reproduction of Rations Balanced from Restricted Sources 175-198
Steer, influence of—
  kind of feed on rate of passage through 60
  moisture of feces on digestion 55-56
  quantity of feed on rate of passage through. 60, 61
  rate of passage of feed on digestion 60-61
Stemrust. See *Puccinia graminis*.
Stewart, R., and Peterson, W. (paper): Origin of Alkali 331-353
Studies on Oat Breeding—V: The F_1 and F_2 Generations of a Cross between a Naked and a Hulled Oat (paper) 293-312
Study of the Proteins of Certain Insects with Reference to their Value as Food for Poultry, A (paper) 633-637
Study of the Rate of Passage of Food Residues through the Steer and Its Influence on Digestion Coefficients, A (paper) 55-63
Substitute for Litmus for Use in Milk Cultures, A (paper) 105-111
Sugar, percentage in alfalfa silage 291
Sulphate, nicotine. See Nicotine sulphate.
Sulphuric acid. See Acid, sulphuric.
Surface, F. M., and Zinn, J. (paper): Studies on Oat Breeding—V: The F_1 and F_2 Generations of a Cross between a Naked and a Hulled Oat 293-312
Swanson, C. O., and Tague, E. L. (paper): Chemical Studies in Making Alfalfa Silage 275-292
Sweet alyssum. See *Koniga maritima*.

Page

Tague, E. L., and Swanson, C. O. (paper): Chemical Studies in Making Alfalfa Silage 275–292
Tarsonemus—
pallidus—
control 387–389
description 378–383
dissemination 377
distribution 375
history 373–374
host plant 377
injury from 378
life history 383–386
nomenclature 375–376
rearing 386–387
systematic relationship 376
spp., cause of plant diseases 377
Temperature—
effect on microorganisms in silage 75–83
effect on evaporation 218–239, 253
index of volatility of compounds to insects. 370
Terpinol, toxicity to insects 367, 369
Tetracarbonimid, comparison with cyanuric acid 87–88
Thiophene, toxicity to insects 367, 368, 370
Thomas, H. E., and Fromme, F. D. (paper): Black Rootrot of the Apple 163–174
Thuja—
occidentalis, host of *Phoma* sp 538
orientalis, host of *Phoma* sp 538
plicata, host of *Phoma* sp 538
Thymol, toxicity to insects 368, 370
Time, influence on passage of feed through steer 55–63
Tobacco. See *Nicotiana tabacum*.
Tobacco spray. See Nicotine sulphate.
Toluene, toxicity to insects 367, 369, 370
Toughness of Bituminous Aggregates (paper) 319–330
Toxic Values and Killing Efficiency of the Arsenates (paper) 199–207
Toxicity, organic compounds, relation to volatility 365–371
Triticum spp.—
distribution of new disease of 51
control of new disease of 53
effect of boron on 591–597
effect on—
growth of cattle 176–197
milk secretion of cattle 179–197
reproduction of cattle 179–197
probable cause of new disease of 52
symptoms of new disease of 52
Turnip. See *Brassica rapa*.
Turpin, H. W., and Harris, F. S. (paper): Movement and Distribution of Moisture in the Soil 113–155
Two New Cámbium Miners, Diptera (paper) 313–318

Ulmus—
americana, host plant of *Eriosoma pyricola*. 68
campestris, host plant of *Eriosoma pyricola*. 68
Uredinia of *Puccinia graminis*—
appearance 486–487
development 486–487
Urediniospores of *Puccinia graminis*—
morphology 484–488
results of inoculation on various hosts 432–484

Page

Valeric acid. See Acid, valeric.
Vitamines, effect on—
milk secretion in cattle 187–189
reproduction of cattle 187–189
growth of cattle 187–189
Volatility of Organic Compounds as an Index of the Toxicity of Their Vapors to Insects (paper) 365–371

Walters, E. H., and Wise, L. E. (paper): Isolation of Cyanuric Acid from Soil 85–92
Water—
absorption by plant from soil 41–42
effect of source of supply on soil moisture 149–150
evaporation—
accuracy of measurements 216–217
description of tanks used for 249
Effect of—
location on 218–238, 250–259
size of water surfaces on 218–259
stream-bed materials on 242–259
temperature on 218–239, 253
weather 241–242
wind velocity 239–241
effect on irrigation 309
flowing, effect on evaporation 227–229
movement in soil in relation to—
hygroscopicity 391–428
initial moistness 391–428
solvent of quassiin powder 510–514
still, effect on evaporation 227–229
variation in leaves of—
Andropogon sorghum 11–46
Zea mays 11–46
Watercress. See *Radicula sinuata*.
Watercress, wild. See *Roripa sinuata*.
Weather—
effect on—
disease dissemination 639–648
evaporation 241–242
soil moisture 119–120, 130–131, 152
relation of, to moisture from surface soil 418
Weir, J. R. (paper): A Needle Blight of Douglas Fir 99–104
Wheat. See *Triticum* spp.
Wilson, J. B., and Cook, F. C. (paper): Effect of Three Annual Applications of Boron on Wheat 591–597
Wilting, influence on alfalfa silage 278–279
Wind—
factor in disease dissemination 639–648
velocity of, effect on evaporation 239–241
Wind-Blown Rain, a Factor in Disease Dissemination (paper) 639–648
Wise, L. E., and Walters, E. H. (paper): Isolation of Cyanuric Acid from Soil 85–92
Woolly pear aphis. See *Eriosoma pyricola*.

Xylaria rootrot. See Rootrot, black.
Xylaria spp.—
causal organisms of black rootrot of *Malus sylvestris* 166–172
culture features 167–168
inoculations of *Malus sylvestris* with 168–170
pathogenicity 168
See also Rootrot, black.
Xylene, toxicity to insects 367, 369, 370

Zea mays— Page
composition 600
digestibility 608-609
effect on—
growth of cattle 176-197
milk secretion of cattle 179-197
reproduction of cattle 179-197
energy values 599-613
moisture content of soil 12
Zea mays—Continued Page
variation of—
dry matter in leaves 11-46
water in leaves 11-49
Zinn, J. and Surface, F. M. (paper): Studies on Oat Breeding—V: The F_1 and F_2 Generations of a Cross Between a Naked and a Hulled Oat 293-312

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